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# The Building Trades Handbook

A CONVENIENT REFERENCE BOOK
ON BUILDING CONSTRUCTION

TREATING OF

Mathematics, Geometrical Drawing, Structural Design, Masonry, Brickwork, Terra-Cotta Masonry, Fireproofing, Carpentry, Joinery, Roofing, Plastering, Estimating, and the Elements of Architectural Design

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BY

International Correspondence Schools
SCRANTON, PA.

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*3d Edition, 224th Thousand, 28th Impression*

SCRANTON, PA.
INTERNATIONAL TEXTBOOK COMPANY
1920

PRESS OF
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.

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# PREFACE

This Handbook is intended for the use of persons interested in the Building Trades, especially in Masonry, Carpentry, Structural Steel, Roofing, etc.; also for the use of Architects and Draftsmen. It contains brief but comprehensive treatments of such subjects as Mathematics, including tables of powers and roots, weights and measures, metric system, formulas, mensuration and circumferences and areas of circles; Geometrical Drawing, giving solutions of many common problems; Structural Design, including articles on live and dead loads, strength of materials, properties of sections, design of beams, girders, columns of wood, steel, and concrete, principles of stresses, design of trusses, arches, and retaining walls.

Also there are chapters on Materials, in which their characteristics, sizes, colors, durability, and methods of application are discussed. The material on Plumbing, Heating, and Ventilating in this Handbook is of a general nature and will be found very useful to the architect or to any other person in laying out plans.

In this edition new material has been introduced on the subjects of Architectural and Structural Terra Cotta, Hollow Tile Construction, the use of Face Brick, Fireproofing, Carpentry and Joinery, and the Elements of Architecture.

The chapters on Estimating have been revised with reference to the prices of building materials and labor at the present time, and are as accurate as it is possible to make them. The methods of estimating given, however, are those in general use and are so presented that they may be successfully used with different unit prices. The article on Elements of Design has been made more useful by the addition of plates of the various Roman orders laid out in fractional parts of the diameter of the column instead of in modules and parts.

This Handbook has been prepared under the direction of Mr. W. S. Lowndes, Principal of our School of Architecture. The article on the Steel Square was prepared by Mr. George W. Milnes.

INTERNATIONAL CORRESPONDENCE SCHOOLS

March, 1914 Scranton, Pa.

# INDEX

# The Building Trades Handbook

## MATHEMATICS

### SIGNS USED IN CALCULATION

$+$ *Plus*, indicates *addition;* thus, $10+5$ is 15.

$-$ *Minus*, indicates *subtraction;* thus, $10-5$ is 5.

$\times$ *Multiplied by*, indicates *multiplication;* thus, $10\times 5$ is 50.

$\div$ *Divided by*, indicates *division;* thus, $10\div 5$ is 2.

$=$ *Equal to*, indicates *equality;* thus, 12 in. = 1 ft.

*Parentheses* ( ), *brackets* [ ], and *braces* { } have the same meaning, and signify that the operations indicated within them are to be performed first. If more than one is used, that indicated in the inner one is to be effected first. Thus, in the expression $5(7-2)$, the subtraction is to be made before multiplying by 5. Again, in the expression $\frac{1}{2}\left[a+\left(b-\frac{c}{4}\right)\right]$, the subtraction indicated within the parentheses is made first; the remainder is added to $a$, and one-half the sum found.

The *vinculum* —— is used for the same purpose as parentheses, but chiefly in connection with the sign $\sqrt{}$; thus, $\sqrt{\phantom{xx}}$.

The *decimal point* . is placed in a number containing decimals, to fix the value of the number; thus, 12.5 is 12 and $\frac{5}{10}$; 1.25 is 1 and $\frac{25}{100}$; etc.

The *exponent* is a small figure placed to the right and a little above a number,—it means the number is to be raised to the power indicated by the small figure; thus, $8^2=8\times 8=64$.

The *radical sign* $\sqrt{\ }$, means that some root of the expression under it is to be found. The vinculum is generallly used in connection with this sign and extends over the number affected by the radical sign. If used without a small index figure, it means square root; thus, $\sqrt{64}=8$. $\sqrt[3]{\ }$ $\sqrt[4]{\ }$ means that the *cube* root or the *fourth* root is to be found, the index figure indicating the root; thus, $\sqrt[3]{27}=3$.

The signs : : : : indicate proportion; thus, 3 : 4 : : 6 : 8 is read 3 *is to* 4 *as* 6 *is to* 8. Instead of the : : sign, the equality sign = is *often* substituted; thus, 3 : 4 = 6 : 8.

The signs ° ′ ″ mean degrees, minutes, and seconds; as 60° 15′ 15″, which is read *60 degrees, 15 minutes, 15 seconds.*

The signs ′ ″ also mean feet and inches; thus, 7′ 6″ is read *7 feet 6 inches.*

The symbol $\pi$ (read *pi*) means the ratio of the circumference of a circle to the diameter and $=3.1416$.

The symbol $\Sigma$ (read *sigma*) means *summation;* thus, $\Sigma(a+b)$ means that there are several values for both $a$ and $b$, and that the sum of all is to be found.

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# FRACTIONS

## COMMON FRACTIONS

The *numerator* of a fraction is the number above the bar; and the *denominator* is the number beneath it; thus, in the fraction $\frac{3}{4}$, 3 is the numerator and 4 is the denominator. Two or more fractions having the same denominator are said to have a *common* denominator.

By *reducing fractions to a common denominator* is meant finding such a denominator as will contain each of the given denominators without a remainder, and multiplying each numerator by the number of times its denominator is contained in the common denominator. Thus, the fractions $\frac{1}{4}$, $\frac{7}{8}$, and $\frac{9}{16}$ have, as a common denominator, 16; then $\frac{1}{4}=\frac{4}{16}$; $\frac{7}{8}=\frac{14}{16}$; $\frac{9}{16}=\frac{9}{16}$.

By *reducing a fraction to its lowest terms* is meant dividing both numerator and denominator by the greatest number that each will contain without a remainder; for example, in $\frac{14}{16}$, the

greatest number that will thus divide 14 and 16 is 2; so that $\frac{14 \div 2}{16 \div 2} = \frac{7}{8}$, which is $\frac{14}{16}$ reduced to the lowest terms.

A *mixed number* is one consisting of a whole number and a fraction, as $7\frac{3}{8}$.

An *improper fraction* is one in which the numerator is equal to, or greater than, the denominator, as $\frac{17}{8}$. This is reduced to a mixed number by dividing 17 by 8, giving $2\frac{1}{8}$. If the numerator is less than the denominator, the fraction is termed *proper*. A mixed number is reduced to a fraction by multiplying the whole number by the denominator, adding the numerator, and placing the sum over the denominator; thus, $1\frac{7}{8} = \frac{(1 \times 8) + 7}{8} = \frac{15}{8}$.

**Addition of Fractions or Mixed Numbers.**—If fractions only are to be added, reduce them to a common denominator, and place the sum of the numerators over the common denominator. If mixed numbers are to be added, add the sum of the fractions to that of the whole numbers; thus, $1\frac{7}{8} + 2\frac{1}{4} = (1+2) + (\frac{7}{8} + \frac{2}{8}) = 4\frac{1}{8}$.

**Subtraction of Fractions or Mixed Numbers.**—If there are fractions only, reduce them to a common denominator, take less from greater, and reduce result; as, $\frac{7}{8}$ in. $- \frac{9}{16}$ in. $= \frac{14-9}{16} = \frac{5}{16}$ in.

If there are mixed numbers, subtract fractions and whole numbers separately, placing remainders beside one another; thus, $3\frac{7}{8}$ in. $- 2\frac{1}{4}$ in. $= (3-2) + (\frac{7}{8} - \frac{2}{8}) = 1\frac{5}{8}$ in. With fractions like the following, proceed as indicated: $3\frac{7}{16}$ in. $- 1\frac{13}{16}$ in. $= (2 + \frac{16}{16} + \frac{7}{16}) - 1\frac{13}{16} = 2\frac{23}{16} - 1\frac{13}{16} = 1\frac{10}{16} = 1\frac{5}{8}$ in.; 7 in. $- 4\frac{3}{4}$ in. $= (6 + \frac{4}{4}) - 4\frac{3}{4} = 2\frac{1}{4}$ in.

**Multiplication of Fractions.**—Multiply the numerators together, and likewise the denominators, and divide the former by the latter; thus, $\frac{1}{2}$ in. $\times \frac{3}{4}$ in. $\times \frac{5}{8}$ in. $= \frac{1 \times 3 \times 5}{2 \times 4 \times 8} = \frac{15}{64}$ cu. in.

If mixed numbers are to be multiplied, reduce to fractions, and proceed as shown; thus, $1\frac{1}{2}$ in. $\times 3\frac{1}{4}$ in. $= \frac{3}{2} \times \frac{13}{4} = \frac{39}{8} = 4\frac{7}{8}$ sq. in.

**Division of Fractions.**—Invert the divisor (exchange places of numerator and denominator) and multiply the dividend by

it, reducing the result, if necessary; thus, $\frac{7}{8} \div \frac{3}{4} = \frac{7}{8} \times \frac{4}{3} = \frac{28}{24} = \frac{7}{6} = 1\frac{1}{6}$. If there are mixed numbers, reduce them to fractions, and divide as shown; thus, $1\frac{5}{8} \div 3\frac{1}{4} = \frac{13}{8} \div \frac{13}{4}$, or $\frac{13}{8} \times \frac{4}{13} = \frac{52}{104} = \frac{1}{2}$.

## DECIMAL FRACTIONS

In decimals, whole numbers are divided into tenths, hundredths, etc.; thus, $\frac{1}{10}$ is written .1; .08 is read $\frac{8}{100}$, the value of the number being indicated by the position of the decimal point; that is, one figure after the decimal point is read as so many tenths; two figures as so many hundredths; etc. Moving the decimal point to the right multiplies the number by 10 for every place the point is moved; moving it to the left divides the number by 10 for every place the point is moved. Thus, in 125.78 (read 125 and $\frac{78}{100}$), if the decimal point is moved one place to the right, the result is 1,257.8, which is 10 times the first number; or, if the point is moved to the left one place, the result is 12.578 which is $\frac{1}{10}$ the first number, moving the point being equivalent to dividing 125.78 by 10.

Annexing a cipher to the right of a decimal does not change its value; but each cipher inserted between the decimal point and the decimal divides the decimal by 10; thus, in 125.078, the decimal part is $\frac{1}{10}$ of .78.

**Addition of Decimals.**—Place the numbers so that the decimal points are in a vertial line, and add in the ordinary way, placing the decimal point of the sum under the other points.

$$\begin{array}{r} 101.257 \\ 12.965 \\ 43.005 \\ 920.600 \\ \hline 1{,}077.827 \end{array}$$

**Subtraction of Decimals.**—Place the number to be subtracted with its decimal point under that of the other number, and subtract.

$$\begin{array}{r} 917.678 \\ 482.710 \\ \hline 434.968 \end{array}$$

**Multiplication of Decimals.**—Multiply in the ordinary way, and point off from the right of the result as many figures as there are figures to the right of the decimal points in both numbers multiplied. Thus, as there are three figures to the right of the points, point off that many in the result. If either number contains no decimal, point off as many places in the product as there are decimal places in the other number.

$$\begin{array}{r} 21.72 \\ 34.1 \\ \hline 2172 \\ 8688 \\ 6516 \\ \hline 740.652 \end{array}$$

If a result has not as many figures as the sum of the decimal places in the numbers multiplied, enough ciphers must be prefixed to the figures to make up the required number of places, and the decimal point placed before the ciphers. Thus, in $.002 \times .002$, the product of $2 \times 2 = 4$; but there are three places in each number; hence, the product must have six places, and five ciphers must be prefixed to the 4, which gives .000004.

**Division of Decimals.**—Divide in the usual way. If the dividend has more decimal places than the divisor, point off, from the right of the quotient, the number of places in excess. If it has less than the divisor, annex as many ciphers to the decimal as are necessary to give the dividend as many places as there are in the divisor; the quotient will then have no decimal places. For example, $\frac{25.75}{2.5} = 10.3$; $\frac{82.5}{2.75} = \frac{82.50}{2.75} = 30$; $\frac{7.5}{2.5} = 3$.

To carry a division to any number of decimal places, annex ciphers to the dividend, and divide, until the desired number of figures in the quotient is reached, which are pointed off as just shown. Thus, $36.5 \div 18.1$ to three decimal places $= \frac{36.5000}{18.1} = 2.016+$. (The sign + thus placed after a number indicates that the exact result would be more than the one given if the division were carried further.)

**Reducing a Decimal to a Common Fraction.**—Use the significant figure, or figures, of the decimal as the numerator; and for the denominator put 1 with as many ciphers as there are figures to the right of the decimal point. For example, .075 has three figures to the right of the point; hence, $.075 \text{ ft.} = \frac{75}{1{,}000} = \frac{3}{40}$ ft.

**Reducing a Common Fraction to a Decimal.**—Divide the numerator by the denominator, and point off as many places as there have been ciphers annexed; thus, $\frac{3}{16}$ in. $= 3.0000 \div 16 = .1875$ in.

## INVOLUTION

*Involution* is the process of multiplying a number by itself one or more times, the product obtained being called a certain *power* of the number.

If the number is multiplied by itself, the result is called the *square* of the number; thus, 9 is the square of 3, since $3\times3=9$.

If the square of a number is multiplied by the number, the result is called the *cube* of the number; thus, 27 is the cube of 3, since $3\times3\times3=27$.

The power to which a number is to be raised is indicated by a small figure, called an *exponent*, placed to the right and a little above the number; thus, $7^2$ means that 7 is to be squared; $27^3$ means that 27 is to be cubed, etc.

The operations of involution present no difficulty, as nothing but multiplication is involved, the number of times the number is to be taken as a factor being shown by the exponent. If the number is a fraction, raise both numerator and denominator to the power indicated.

A valuable little rule to memorize for finding the square of a mixed number in which the fraction is $\frac{1}{2}$, as $3\frac{1}{2}$, $10\frac{1}{2}$, etc., is as follows:

**Rule.**—*Multiply the next less whole number by the next greater, and add* $\frac{1}{4}$.

For example, the square of $6\frac{1}{2}$ is 6 (the next less number) $\times 7$ (the next greater) $+\frac{1}{4}=42\frac{1}{4}$; $(19\frac{1}{2})^2=19\times20+\frac{1}{4}=380\frac{1}{4}$; $(8\frac{1}{2})^2=8\times9+\frac{1}{4}=72\frac{1}{4}$, etc.

## EVOLUTION

*Evolution* is the reverse of involution and is the process of finding one of the equal factors of a number, termed a *root*, which, multiplied by itself a certain number of times, will give a product equal to the given number. When the number is to be resolved into two equal factors, either one is called the *square root;* when there are to be three equal factors, each one is called the *cube root;* etc.

The operations to be performed are indicated by the radical sign $\sqrt{\phantom{x}}$ and vinculum $\overline{\phantom{xxx}}$, and by an index figure; for square

root, the index figure is omitted. For example, $\sqrt{64}$ is read the square root of 64, which is 8, as $8\times8=64$; $\sqrt[3]{64}$ means cube root of 64, which is 4, as $4\times4\times4=64$.

A number is said to be a *perfect square*, or a *perfect cube*, etc. when the root consists only of a whole number; thus, 64 is a perfect cube, because the cube root is 4, without any decimal.

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# TABLE OF POWERS, ROOTS, AND RECIPROCALS

## SIGNIFICANT FIGURES

By means of the following table the square, cube, square root, cube root, and reciprocal of any number may be obtained correct always to five significant figures, and in the majority of cases correct to six significant figures.

In any number, the figures beginning with the first digit* at the left and ending with the last digit at the right, are called the *significant figures* of the number. Thus, the number 405,800 has the four significant figures 4, 0, 5, 8; and the number .000090067 has the five significant figures 9, 0, 0, 6, and 7.

The part of a number consisting of its significant figures is called the *significant part* of the number. Thus, in the number 28,070, the significant part is 2807; in the number .00812, the significant part is 812; and in the number 170.3, the significant part is 1703.

In speaking of the significant figures or of the significant part of a number, the figures are considered, in their proper order, from the first digit at the left to the last digit at the right, but no attention is paid to the position of the decimal point. Hence, all numbers that differ only in the position of the decimal point have the same significant part. For example, .002103, 21.03, 21.030, and 210,300 have the same significant figures 2, 1, 0, and 3, and the same significant part 2103.

The *integral part* of a number is the part to the left of the decimal point.

It will be more convenient to explain first how to use the table for finding square and cube roots.

*A cipher is not a digit.

## SQUARE ROOT

To obtain the square root of a number, first point off the given number into periods of two figures each, beginning with the decimal point and proceeding to the left and right; for example, 12703, 1'27'03; 12.703, 12.70'30; 220000, 22'00'00; .000442, .00'04'42. Then, having pointed off the number, move the decimal point so that it will fall between the first and second periods of the significant part of the number. In the preceding numbers, the decimal point will be placed thus: 1.2703, 12.703, 22, 4.42.

If the number has three or less significant figures, find the significant part of the number in the column headed $n$; the square root will be found in the column headed $\sqrt{n}$ or $\sqrt{10n}$, according to whether the part to the left of the decimal point contains one figure or two figures. Thus, $\sqrt{4.42}=2.1024$, and $\sqrt{22}=\sqrt{10\times 2.20}=4.6904$. The decimal point is located in all cases by reference to the original number after pointing off into periods.

**Rule.**—*There will be as many figures in the root preceding the decimal point as there are periods preceding the decimal point in the given number; if the number is entirely decimal, the root is entirely decimal, and there will be as many ciphers following the decimal point in the root as there are cipher periods following the decimal point in the given number.*

Applying this rule, $\sqrt{220000}=469.04$ and $\sqrt{.000442}=.021024$.

The operation when the given number has more than three significant figures is best explained by an example.

EXAMPLE.—(*a*) $\sqrt{3.1416}=?$ (*b*) $\sqrt{2342.9}=?$

SOLUTION.—(*a*) As the first period contains but one figure, there is no need of moving the decimal point. In the column headed $n^2$, find two consecutive numbers, one a little greater and the other a little less than the given number; in the present case, $3.1684=1.78^2$ and $3.1329=1.77^2$. The first three figures of the root are therefore 177. Find the difference between the two numbers between which the given number falls, and the difference between the smaller number and the given number; divide the second difference by the first difference, carrying the quotient to three decimal places and increasing the second figure by 1 if the third is 5 or a greater digit.

The two figures of the quotient thus determined will be the fourth and fifth figures of the root. In the present example, dropping decimal points in the remainders, 3.1684 − 3.1329 = 355, the first difference; 3.1416 − 3.1329 = 87, the second difference; 87 ÷ 355 = .245+, or .25. Hence, $\sqrt{3.1416} = 1.7725$.

(*b*) $\sqrt{2342.9} = ?$ Pointing off into periods gives 23′42.90; moving the decimal point gives 23.4290; the first three figures of the root are 484; the first difference is 23.5225 − 23.4256 = 969; the second difference is 23.4290 − 23.4256 = 34; 34 ÷ 969 = .035+, or .04. Hence, $\sqrt{2342.9} = 48.404$.

## CUBE ROOT

The cube root of a number is found in a manner similar to that used for finding the square root. The difference being that the given number is pointed off into periods of three figures each; for example, 3141.6, 3′141.600; 67296428, 67′296′428; 601426.314, 601′426.314; .0000000217, .000′000′021′700. Then, having pointed off, move the decimal point so that it will fall between the first and second periods of the significant part of the number, as in square root. In the foregoing numbers the decimal point will be placed thus: 3.1416, 67.296428, 601.426314, and 21.7.

If the given number has three or less significant figures, find the significant part of the number in the column headed $n$; the cube root will be found in the column headed $\sqrt[3]{n}$, $\sqrt[3]{10\,n}$, or $\sqrt[3]{100\,n}$, according to whether one, two, or three figures precede the decimal point after it has been moved. Thus, the cube root of 21.7 will be found opposite 2.17, in column headed $\sqrt[3]{10\,n}$; the cube root of 2.17 will be found in the column headed $\sqrt[3]{n}$; and the cube root of 217, in the column headed $\sqrt[3]{100\,n}$, all on the same line. If the given number contains more than three significant figures, proceed exactly as described for square root except that the column headed $n^3$ is used.

Example.—(*a*) $\sqrt[3]{.0000062417} = ?$ (*b*) $\sqrt[3]{50932676} = ?$

Solution.—(*a*) Pointing off into periods, gives .000′006′-241′700; moving the decimal point, gives 6.2417. The number falls between $6.22950 = 1.84^3$ and $6.33163 = 1.85^3$; the first difference = 10213; the second difference is 6.24170 − 6.22950 = 1220; 1220 ÷ 10213 = .119+, or .12, the fourth and fifth

figures of the root. The decimal point is located by the rule previously given; hence, $\sqrt[3]{.0000062417} = .018412$.

(*b*) $\sqrt[3]{50932676} = ?$ As the number contains more than six significant figures, reduce it to six significant figures by replacing all after the sixth figure with ciphers, increasing the sixth figure by 1 when the seventh is 5 or a greater digit. In other words, the first five figures of $\sqrt[3]{50932700}$ and of $\sqrt[3]{50932676}$ are the same. Pointing off into periods, gives 50′932′700; moving the decimal point, gives 50.9327, which falls between $50.6530 = 3.70^3$ and $51.0648 = 3.71^3$; the first difference is 4118; the second difference is 2797; $2797 \div 4118 = .679+$, or .68. The integral part of the root evidently contains three figures; hence, $\sqrt[3]{50932676} = 370.68$, correct to five figures.

## SQUARES AND CUBES

If the given number contains three or less significant figures, the square or cube is found in the column headed $n^2$ or $n^3$, opposite the given number in the column headed $n$. To find the square of a given number containing more than three significant figures, place the decimal point between the first and second significant figures and find in the column headed $\sqrt{n}$ or $\sqrt{10\,n}$ two consecutive numbers, one of which is a little greater and the other a little less than the given number. The remainder of the work is very similar to that described for extracting roots.

To locate the decimal point, employ the principle that the square of any number contains either twice as many figures as the number squared or twice as many less one. If the column headed $\sqrt{10\,n}$ is used, the square will contain twice as many figures, while if the column headed $\sqrt{n}$ is used, the square will contain twice as many figures as the number squared, less one. If the number contains an integral part, this principle is applied to the integral part only; if the number is wholly decimal, there will be twice as many ciphers following the decimal point in the square or twice as many plus one, as in the number squared, depending on whether $\sqrt{10\,n}$ or $\sqrt{n}$ column is used. For example, $273.42^2$ will contain five figures in the integral part; $4516.2^2$ will contain eight figures in the integral part, all after the fifth being denoted by ciphers;

$.0029453^2$ will have five ciphers following the decimal point; $.052436^2$ will have two ciphers following the decimal point.

EXAMPLE.—(*a*) $273.42^2 = ?$ (*b*) $.052436^2 = ?$

SOLUTION.—(*a*) Placing the decimal point between the first and second significant figures, the result is 2.7342; this number occurs between $2.73313 = \sqrt{7.47}$ and $2.73496 = \sqrt{7.48}$ in the column headed $\sqrt{n}$. The first difference is $2.73496 - 2.73313 = 183$; the second difference is $2.73420 - 2.73313 = 107$; and $107 \div 183 = .584+$, or .58. Hence, $273.42^2 = 74{,}758$, correct to five significant figures.

(*b*) Shifting the decimal point to between the first and second significant figures, gives the number 5.2436, which falls between $5.23450 = \sqrt{27.4}$ and $5.24404 = \sqrt{27.5}$. The first difference is 954; the second difference is 910; $910 \div 954 = .953+$, or .95. Hence, $.052436^2 = .0027495$, when carried to five significant figures.

A number is cubed in exactly the same manner, using the column headed $\sqrt[3]{n}$, $\sqrt[3]{10\,n}$, or $\sqrt[3]{100\,n}$, according to whether the first period of the significant part of the number contains one, two, or three figures, respectively. If the number contains an integral part, the number of figures in the integral part of the cube will be three times as many as in the given number if column headed $\sqrt[3]{100\,n}$ is used; it will be three times as many less 1 if the column headed $\sqrt[3]{10\,n}$ is used; and it will be three times as many less 2 if the column headed $\sqrt[3]{n}$ is used. If the given number is wholly decimal the cube will have three times, three times plus 1, or three times plus 2, as many ciphers following the decimal point as there are ciphers following the decimal point in the given number, depending on whether the $\sqrt[3]{100\,n}$, the $\sqrt[3]{10\,n}$, or the $\sqrt[3]{n}$ column is used.

EXAMPLE.—(*a*) $129.684^3 = ?$ (*b*) $.76442^3 = ?$ (*c*) $.032425^3 = ?$

SOLUTION.—(*a*) Placing the decimal point between the first and second significant figures, the number 1.29684 is found between $1.29664 = \sqrt[3]{2.18}$ and $1.29862 = \sqrt[3]{2.19}$. The first difference is 198; the second difference is 20; and $20 \div 198 = .101+$, or .10. Hence, the first five significant figures are 21810; the number of figures in the integral part of the cube is $3 \times 3 - 2 = 7$; and $129.684^3 = 2{,}181{,}000$, correct to five significant figures.

(*b*) 7.64420 occurs between $7.64032 = \sqrt[3]{446}$ and $7.64603 = \sqrt[3]{447}$. The first difference is 571; the second difference is 388; and $388 \div 571 = .679+$, or .68. Hence, the first five significant figures are 44668; the number of ciphers following the decimal point is $3 \times 0 = 0$; and $.76442^3 = .44668$, correct to five significant figures.

(*c*) 3.2425 falls between $3.24278 = \sqrt[3]{34.1}$ and $3.23961 = \sqrt[3]{34.0}$. The first difference is 317; the second difference is 289; $289 \div 317 = .911+$, or .91. Hence, the first five significant figures are 34091; the number of ciphers following the decimal point is $3 \times 1 + 1 = 4$; and $.032425^3 = .000034091$, correct to five significant figures.

## RECIPROCALS

The *reciprocal* of a number is 1 divided by the number. By using reciprocals, division is changed into multiplication, as $a \div b = \frac{a}{b} = a \times \frac{1}{b}$. The table gives the reciprocals of all numbers, expressed with three significant figures, correct to six significant figures. By proceeding in a manner similar to that just described for powers and roots, the reciprocal of any number, correct to five significant figures, may be obtained.

The decimal point in the result may be located as follows: If the given number has an integral part, the number of ciphers following the decimal point in the reciprocal will be one less than the number of figures in the integral part of the given number; and if the given number is entirely decimal, the number of figures in the integral part of the reciprocal will be one greater than the number of ciphers following the decimal point in the given number. For example, the reciprocal of 3370 = .000296736 and of .00348 = 287.356.

When the number whose reciprocal is desired contains more than three significant figures, express the number to six significant figures (adding ciphers, if necessary, to make six figures) and find between what two numbers in the column headed $\frac{1}{n}$ the significant figures of the given number fall; then proceed in a manner similar to that previously described to determine the fourth and fifth figures.

EXAMPLE.—(*a*) What is the reciprocal of 379.426?

(*b*) $\frac{1}{.0004692}=?$

SOLUTION.—(*a*) .379426 falls between $.378788=\frac{1}{2.64}$ and $.380228=\frac{1}{2.63}$. The first difference is $380228-378788=1440$; the second difference is $380228-379426=802$; $802\div 1440=.556+$, or .56. Hence, the first five significant figures are 26356, and the reciprocal of 379.426 is .0026356, to five significant figures.

(*b*) .469200 falls between $.469484=\frac{1}{2.13}$ and $.467290=\frac{1}{2.14}$. The first difference is 2194; the second difference is 284; $284\div 2194=.129+$, or .13. Hence, $\frac{1}{.0004692}=2131.3$, correct to five significant figures.

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10n}$ | $\sqrt[3]{100n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 1.01 | 1.0201 | 1.03030 | 1.00499 | 3.17805 | 1.00332 | 2.16159 | 4.65701 | .990099 |
| 1.02 | 1.0404 | 1.06121 | 1.00995 | 3.19374 | 1.00662 | 2.16870 | 4.67233 | .980392 |
| 1.03 | 1.0609 | 1.09273 | 1.01489 | 3.20936 | 1.00990 | 2.17577 | 4.68755 | .970874 |
| 1.04 | 1.0816 | 1.12486 | 1.01980 | 3.22490 | 1.01316 | 2.18278 | 4.70267 | .961539 |
| 1.05 | 1.1025 | 1.15763 | 1.02470 | 3.24037 | 1.01640 | 2.18976 | 4.71769 | .952381 |
| 1.06 | 1.1236 | 1.19102 | 1.02956 | 3.25576 | 1.01961 | 2.19669 | 4.73262 | .943396 |
| 1.07 | 1 1449 | 1.22504 | 1.03441 | 3.27109 | 1.02281 | 2.20358 | 4.74746 | .934579 |
| 1.08 | 1.1664 | 1.25971 | 1.03923 | 3.28634 | 1.02599 | 2.21042 | 4.76220 | .925926 |
| 1.09 | 1.1881 | 1.29503 | 1.04403 | 3.30151 | 1.02914 | 2.21722 | 4.77686 | .917431 |
| 1.10 | 1.2100 | 1.33100 | 1.04881 | 3.31662 | 1.03228 | 2.22398 | 4.79142 | .909091 |
| 1.11 | 1.2321 | 1 36763 | 1.05357 | 3.33167 | 1.03540 | 2.23070 | 4.80590 | .900901 |
| 1.12 | 1.2544 | 1.40493 | 1.05830 | 3.34664 | 1.03850 | 2.23738 | 4.82028 | .892857 |
| 1.13 | 1.2769 | 1.44290 | 1.06301 | 3.36155 | 1.04158 | 2.24402 | 4.83459 | .884956 |
| 1.14 | 1.2996 | 1.48154 | 1.06771 | 3.37639 | 1.04464 | 2.25062 | 4.84881 | .877193 |
| 1.15 | 1.3225 | 1.52088 | 1.07238 | 3.39116 | 1.04769 | 2.25718 | 4.86294 | .869565 |
| 1.16 | 1.3456 | 1.56090 | 1.07703 | 3.40588 | 1.05072 | 2.26370 | 4.87700 | .862069 |
| 1.17 | 1.3689 | 1.60161 | 1.08167 | 3.42053 | 1.05373 | 2.27019 | 4.89097 | .854701 |
| 1.18 | 1.3924 | 1.64303 | 1.08628 | 3.43511 | 1.05672 | 2.27664 | 4.90487 | .847458 |
| 1.19 | 1.4161 | 1.68516 | 1.09087 | 3.44964 | 1.05970 | 2.28305 | 4.91868 | .840336 |
| 1.20 | 1.4400 | 1.72800 | 1.09545 | 3.46410 | 1.06266 | 2.28943 | 4.93242 | .833333 |
| 1.21 | 1.4641 | 1.77156 | 1.10000 | 3.47851 | 1.06560 | 2.29577 | 4.94609 | .826446 |
| 1.22 | 1.4884 | 1.81585 | 1.10454 | 3.49285 | 1.06853 | 2.30208 | 4.95968 | .819672 |
| 1.23 | 1.5129 | 1.86087 | 1.10905 | 3.50714 | 1.07144 | 2.30835 | 4.97319 | .813008 |
| 1.24 | 1.5376 | 1.90662 | 1.11355 | 3.52136 | 1.07434 | 2.31459 | 4.98663 | .806452 |
| 1.25 | 1.5625 | 1.95313 | 1.11803 | 3.53553 | 1.07722 | 2.32080 | 5.00000 | .800000 |
| 1.26 | 1.5876 | 2.00038 | 1.12250 | 3.54965 | 1.08008 | 2.32697 | 5.01330 | .793651 |
| 1.27 | 1.6129 | 2.04838 | 1.12694 | 3.56371 | 1.08293 | 2.33310 | 5.02653 | .787402 |
| 1.28 | 1.6384 | 2.09715 | 1.13137 | 3.57771 | 1.08577 | 2.33921 | 5.03968 | .781250 |
| 1.29 | 1.6641 | 2.14669 | 1.13578 | 3.59166 | 1.08859 | 2.34529 | 5.05277 | .775194 |
| 1.30 | 1.6900 | 2.19700 | 1.14018 | 3.60555 | 1.09139 | 2.35134 | 5.06580 | .769231 |
| 1.31 | 1.7161 | 2.24809 | 1.14455 | 3.61939 | 1.09418 | 2.35735 | 5.07875 | .763359 |
| 1.32 | 1.7424 | 2.29997 | 1.14891 | 3.63318 | 1.09696 | 2.36333 | 5.09164 | .757576 |
| 1.33 | 1.7689 | 2.35264 | 1.15326 | 3.64692 | 1.09972 | 2.36928 | 5.10447 | .751880 |
| 1.34 | 1.7956 | 2.40610 | 1.15758 | 3.66060 | 1.10247 | 2.37521 | 5.11723 | .746269 |
| 1.35 | 1.8225 | 2.46038 | 1.16190 | 3.67423 | 1.10521 | 2.38110 | 5.12993 | .740741 |
| 1.36 | 1.8496 | 2.51546 | 1.16619 | 3.68782 | 1.10793 | 2.38696 | 5.14256 | .735294 |
| 1.37 | 1.8769 | 2.57135 | 1.17047 | 3.70135 | 1.11064 | 2.39280 | 5.15514 | .729927 |
| 1.38 | 1.9044 | 2.62807 | 1.17473 | 3.71484 | 1.11334 | 2.39861 | 5.16765 | .724638 |
| 1.39 | 1.9321 | 2.68562 | 1.17898 | 3.72827 | 1.11602 | 2.40439 | 5.18010 | .719425 |
| 1.40 | 1.9600 | 2.74400 | 1.18322 | 3.74166 | 1.11869 | 2.41014 | 5.19249 | .714286 |
| 1.41 | 1.9881 | 2.80322 | 1.18743 | 3.75500 | 1.12135 | 2.41587 | 5.20483 | .709220 |
| 1.42 | 2.0164 | 2.86329 | 1.19164 | 3.76829 | 1.12399 | 2.42156 | 5.21710 | .704225 |
| 1.43 | 2.0449 | 2.92421 | 1.19583 | 3.78153 | 1.12662 | 2.42724 | 5.22932 | .699301 |
| 1.44 | 2.0736 | 2.98598 | 1.20000 | 3.79473 | 1.12924 | 2.43288 | 5.24148 | .694444 |
| 1.45 | 2.1025 | 3.04863 | 1.20416 | 3.80789 | 1.13185 | 2.43850 | 5.25359 | .689655 |
| 1.46 | 2.1316 | 3.11214 | 1.20830 | 3.82099 | 1.13445 | 2.44409 | 5.26564 | .684932 |
| 1.47 | 2.1609 | 3.17652 | 1.21244 | 3.83406 | 1.13703 | 2.44966 | 5.27763 | .680272 |
| 1.48 | 2.1904 | 3.24179 | 1.21655 | 3.84708 | 1.13960 | 2.45520 | 5.28957 | .675676 |
| 1.49 | 2.2201 | 3.30795 | 1.22066 | 3.86005 | 1.14216 | 2.46072 | 5.30146 | .671141 |
| 1.50 | 2.2500 | 3.37500 | 1.22474 | 3.87298 | 1.14471 | 2.46621 | 5.31329 | .666667 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10n}$ | $\sqrt[3]{100n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 1.51 | 2.2801 | 3.44295 | 1.22882 | 3.88587 | 1.14725 | 2.47168 | 5.32507 | .662252 |
| 1.52 | 2.3104 | 3.51181 | 1.23288 | 3.89872 | 1.14978 | 2.47713 | 5.33680 | .657895 |
| 1.53 | 2.3409 | 3.58158 | 1.23693 | 3.91152 | 1.15230 | 2.48255 | 5.34848 | .653595 |
| 1.54 | 2.3716 | 3.65226 | 1.24097 | 3.92428 | 1.15480 | 2.48794 | 5.36011 | .649351 |
| 1.55 | 2.4025 | 3.72388 | 1.24499 | 3.93700 | 1.15729 | 2.49332 | 5.37169 | .645161 |
| 1.56 | 2.4336 | 3.79642 | 1.24900 | 3.94968 | 1.15978 | 2.49866 | 5.38321 | .641026 |
| 1.57 | 2.4649 | 3.86989 | 1.25300 | 3.96232 | 1.16225 | 2.50399 | 5.39469 | .636943 |
| 1.58 | 2.4964 | 3.94431 | 1.25698 | 3.97492 | 1.16471 | 2.50930 | 5.40612 | .632911 |
| 1.59 | 2.5281 | 4.01968 | 1.26095 | 3.98748 | 1.16717 | 2.51458 | 5.41750 | .628931 |
| 1.60 | 2.5600 | 4.09600 | 1.26491 | 4.00000 | 1.16961 | 2.51984 | 5.42884 | .625000 |
| 1.61 | 2.5921 | 4.17328 | 1.26886 | 4.01248 | 1.17204 | 2.52508 | 5.44012 | .621118 |
| 1.62 | 2.6244 | 4.25153 | 1.27279 | 4.02492 | 1.17446 | 2.53030 | 5.45136 | .617284 |
| 1.63 | 2.6569 | 4.33075 | 1.27671 | 4.03733 | 1.17687 | 2.53549 | 5.46256 | .613497 |
| 1.64 | 2.6896 | 4.41094 | 1.28062 | 4.04969 | 1.17927 | 2.54067 | 5.47370 | .609756 |
| 1.65 | 2.7225 | 4.49213 | 1.28452 | 4.06202 | 1.18167 | 2.54582 | 5.48481 | .606061 |
| 1.66 | 2.7556 | 4.57430 | 1.28841 | 4.07431 | 1.18405 | 2.55095 | 5.49586 | .602410 |
| 1.67 | 2.7889 | 4.65746 | 1.29228 | 4.08656 | 1.18642 | 2.55607 | 5.50688 | .598802 |
| 1.68 | 2.8224 | 4.74163 | 1.29615 | 4.09878 | 1.18878 | 2.56116 | 5.51785 | .595238 |
| 1.69 | 2.8561 | 4.82681 | 1.30000 | 4.11096 | 1.19114 | 2.56623 | 5.52877 | .591716 |
| 1.70 | 2.8900 | 4.91300 | 1.30384 | 4.12311 | 1.19348 | 2.57128 | 5.53966 | .588235 |
| 1.71 | 2.9241 | 5.00021 | 1.30767 | 4.13521 | 1.19582 | 2.57631 | 5.55050 | .584795 |
| 1.72 | 2.9584 | 5.08845 | 1.31149 | 4.14729 | 1.19815 | 2.58133 | 5.56130 | .581395 |
| 1.73 | 2.9929 | 5.17772 | 1.31529 | 4.15933 | 1.20046 | 2.58632 | 5.57205 | .578035 |
| 1.74 | 3.0276 | 5.26802 | 1.31909 | 4.17133 | 1.20277 | 2.59129 | 5.58277 | .574713 |
| 1.75 | 3.0625 | 5.35938 | 1.32288 | 4.18330 | 1.20507 | 2.59625 | 5.59344 | .571429 |
| 1.76 | 3.0976 | 5.45178 | 1.32665 | 4.19524 | 1.20736 | 2.60118 | 5.60408 | .568182 |
| 1.77 | 3.1329 | 5.54523 | 1.33041 | 4.20714 | 1.20964 | 2.60610 | 5.61467 | .564972 |
| 1.78 | 3.1684 | 5.63975 | 1.33417 | 4.21900 | 1.21192 | 2.61100 | 5.62523 | .561798 |
| 1.79 | 3.2041 | 5.73534 | 1.33791 | 4.23084 | 1.21418 | 2.61588 | 5.63574 | .558659 |
| 1.80 | 3.2400 | 5.83200 | 1.34164 | 4.24264 | 1.21644 | 2.62074 | 5.64622 | .555556 |
| 1.81 | 3.2761 | 5.92974 | 1.34536 | 4.25441 | 1.21869 | 2.62558 | 5.65665 | .552486 |
| 1.82 | 3.3124 | 6.02857 | 1.34907 | 4.26615 | 1.22093 | 2.63041 | 5.66705 | .549451 |
| 1.83 | 3.3489 | 6.12849 | 1.35277 | 4.27785 | 1.22316 | 2.63522 | 5.67741 | .546448 |
| 1.84 | 3.3856 | 6.22950 | 1.35647 | 4.28952 | 1.22539 | 2.64001 | 5.68773 | .543478 |
| 1.85 | 3.4225 | 6.33163 | 1.36015 | 4.30116 | 1.22760 | 2.64479 | 5.69802 | .540541 |
| 1.86 | 3.4596 | 6.43486 | 1.36382 | 4.31277 | 1.22981 | 2.64954 | 5.70827 | .537634 |
| 1.87 | 3.4969 | 6.53920 | 1.36748 | 4.32435 | 1.23201 | 2.65428 | 5.71848 | .534759 |
| 1.88 | 3.5344 | 6.64467 | 1.37113 | 4.33590 | 1.23420 | 2.65900 | 5.72865 | .531915 |
| 1.89 | 3.5721 | 6.75127 | 1.37477 | 4.34741 | 1.23639 | 2.66371 | 5.73879 | .529101 |
| 1.90 | 3.6100 | 6.85900 | 1.37840 | 4.35890 | 1.23856 | 2.66840 | 5.74890 | .526316 |
| 1.91 | 3.6481 | 6.96787 | 1.38203 | 4.37035 | 1.24073 | 2.67307 | 5.75897 | .523560 |
| 1.92 | 3.6864 | 7.07789 | 1.38564 | 4.38178 | 1.24289 | 2.67773 | 5.76900 | .520833 |
| 1.93 | 3.7249 | 7.18906 | 1.38924 | 4.39318 | 1.24505 | 2.68237 | 5.77900 | .518135 |
| 1.94 | 3.7636 | 7.30138 | 1.39284 | 4.40454 | 1.24719 | 2.68700 | 5.78896 | .515464 |
| 1.95 | 3.8025 | 7.41488 | 1.39642 | 4.41588 | 1.24933 | 2.69161 | 5.79889 | .512821 |
| 1.96 | 3.8416 | 7.52954 | 1.40000 | 4.42719 | 1.25146 | 2.69620 | 5.80879 | .510204 |
| 1.97 | 3.8809 | 7.64537 | 1.40357 | 4.43847 | 1.25359 | 2.70078 | 5.81865 | .507614 |
| 1.98 | 3.9204 | 7.76239 | 1.40712 | 4.44972 | 1.25571 | 2.70534 | 5.82848 | .505051 |
| 1.99 | 3.9601 | 7.88060 | 1.41067 | 4.46094 | 1.25782 | 2.70989 | 5.83827 | .502513 |
| 2.00 | 4.0000 | 8.00000 | 1.41421 | 4.47214 | 1.25992 | 2.71442 | 5.84804 | .500000 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10n}$ | $\sqrt[3]{100n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 2.01 | 4.0401 | 8.12060 | 1.41774 | 4.48330 | 1.26202 | 2.71893 | 5.85777 | .497512 |
| 2.02 | 4.0804 | 8.24241 | 1.42127 | 4.49444 | 1.26411 | 2.72343 | 5.86746 | .495050 |
| 2.03 | 4.1209 | 8.36543 | 1.42478 | 4.50555 | 1.26619 | 2.72792 | 5.87713 | .492611 |
| 2.04 | 4.1616 | 8.48966 | 1.42829 | 4.51664 | 1.26827 | 2.73239 | 5.88677 | .490196 |
| 2.05 | 4.2025 | 8.61513 | 1.43178 | 4.52769 | 1.27033 | 2.73685 | 5.89637 | .487805 |
| 2.06 | 4.2436 | 8.74182 | 1.43527 | 4.53872 | 1.27240 | 2.74129 | 5.90594 | .485437 |
| 2.07 | 4.2849 | 8.86974 | 1.43875 | 4.54973 | 1.27445 | 2.74572 | 5.91548 | .483092 |
| 2.08 | 4.3264 | 8.99891 | 1.44222 | 4.56070 | 1.27650 | 2.75014 | 5.92499 | .480769 |
| 2.09 | 4.3681 | 9.12933 | 1.44568 | 4.57165 | 1.27854 | 2.75454 | 5.93447 | .478469 |
| 2.10 | 4.4100 | 9.26100 | 1.44914 | 4.58258 | 1.28058 | 2.75893 | 5.94392 | .476191 |
| 2.11 | 4.4521 | 9.39393 | 1.45258 | 4.59347 | 1.28261 | 2.76330 | 5.95334 | .473934 |
| 2.12 | 4.4944 | 9.52813 | 1.45602 | 4.60435 | 1.28463 | 2.76766 | 5.96273 | .471698 |
| 2.13 | 4.5369 | 9.66360 | 1.45945 | 4.61519 | 1.28665 | 2.77200 | 5.97209 | .469484 |
| 2.14 | 4.5796 | 9.80034 | 1.46287 | 4.62601 | 1.28866 | 2.77633 | 5.98142 | .467290 |
| 2.15 | 4.6225 | 9.93838 | 1.46629 | 4.63681 | 1.29066 | 2.78065 | 5.99073 | .465116 |
| 2.16 | 4.6656 | 10.0777 | 1.46969 | 4.64758 | 1.29266 | 2.78495 | 6.00000 | .462963 |
| 2.17 | 4.7089 | 10.2183 | 1.47309 | 4.65833 | 1.29465 | 2.78924 | 6.00925 | .460830 |
| 2.18 | 4.7524 | 10.3602 | 1.47648 | 4.66905 | 1.29664 | 2.79352 | 6.01846 | .458716 |
| 2.19 | 4.7961 | 10.5035 | 1.47986 | 4.67974 | 1.29862 | 2.79779 | 6.02765 | .456621 |
| 2.20 | 4.8400 | 10.6480 | 1.48324 | 4.69042 | 1.30059 | 2.80204 | 6.03681 | .454546 |
| 2.21 | 4.8841 | 10.7939 | 1.48661 | 4.70106 | 1.30256 | 2.80628 | 6.04594 | .452489 |
| 2.22 | 4.9284 | 10.9410 | 1.48997 | 4.71169 | 1.30452 | 2.81051 | 6.05505 | .450451 |
| 2.23 | 4.9729 | 11.0896 | 1.49332 | 4.72229 | 1.30648 | 2.81472 | 6.06413 | .448431 |
| 2.24 | 5.0176 | 11.2394 | 1.49666 | 4.73286 | 1.30843 | 2.81892 | 6.07318 | .446429 |
| 2.25 | 5.0625 | 11.3906 | 1.50000 | 4.74342 | 1.31037 | 2.82311 | 6.08220 | .444444 |
| 2.26 | 5.1076 | 11.5432 | 1.50333 | 4.75395 | 1.31231 | 2.82728 | 6.09120 | .442478 |
| 2.27 | 5.1529 | 11.6971 | 1.50665 | 4.76445 | 1.31424 | 2.83145 | 6.10017 | .440529 |
| 2.28 | 5.1984 | 11.8524 | 1.50997 | 4.77493 | 1.31617 | 2.83560 | 6.10911 | .438597 |
| 2.29 | 5.2441 | 12.0090 | 1.51327 | 4.78539 | 1.31809 | 2.83974 | 6.11803 | .436681 |
| 2.30 | 5.2900 | 12.1670 | 1.51658 | 4.79583 | 1.32001 | 2.84387 | 6.12693 | .434783 |
| 2.31 | 5.3361 | 12.3264 | 1.51987 | 4.80625 | 1.32192 | 2.84798 | 6.13579 | .432900 |
| 2.32 | 5.3824 | 12.4872 | 1.52315 | 4.81664 | 1.32382 | 2.85209 | 6.14463 | .431035 |
| 2.33 | 5.4289 | 12.6493 | 1.52643 | 4.82701 | 1.32572 | 2.85618 | 6.15345 | .429185 |
| 2.34 | 5.4756 | 12.8129 | 1.52971 | 4.83735 | 1.32761 | 2.86026 | 6.16224 | .427350 |
| 2.35 | 5.5225 | 12.9779 | 1.53297 | 4.84768 | 1.32950 | 2.86433 | 6.17101 | .425532 |
| 2.36 | 5.5696 | 13.1443 | 1.53623 | 4.85798 | 1.33139 | 2.86838 | 6.17975 | .423729 |
| 2.37 | 5.6169 | 13.3121 | 1.53948 | 4.86826 | 1.33326 | 2.87243 | 6.18846 | .421941 |
| 2.38 | 5.6644 | 13.4813 | 1.54272 | 4.87852 | 1.33514 | 2.87646 | 6.19715 | .420168 |
| 2.39 | 5.7121 | 13.6519 | 1.54596 | 4.88876 | 1.33700 | 2.88049 | 6.20582 | .418410 |
| 2.40 | 5.7600 | 13.8240 | 1.54919 | 4.89898 | 1.33887 | 2.88450 | 6.21447 | .416667 |
| 2.41 | 5.8081 | 13.9975 | 1.55242 | 4.90918 | 1.34072 | 2.88850 | 6.22308 | .414938 |
| 2.42 | 5.8564 | 14.1725 | 1.55563 | 4.91935 | 1.34257 | 2.89249 | 6.23168 | .413223 |
| 2.43 | 5.9049 | 14.3489 | 1.55885 | 4.92950 | 1.34442 | 2.89647 | 6.24025 | .411523 |
| 2.44 | 5.9536 | 14.5268 | 1.56205 | 4.93964 | 1.34626 | 2.90044 | 6.24880 | .409836 |
| 2.45 | 6.0025 | 14.7061 | 1.56525 | 4.94975 | 1.34810 | 2.90439 | 6.25732 | .408163 |
| 2.46 | 6.0516 | 14.8869 | 1.56844 | 4.95984 | 1.34993 | 2.90834 | 6.26583 | .406504 |
| 2.47 | 6.1009 | 15.0692 | 1.57162 | 4.96991 | 1.35176 | 2.91227 | 6.27431 | .404858 |
| 2.48 | 6.1504 | 15.2530 | 1.57480 | 4.97996 | 1.35358 | 2.91620 | 6.28276 | .403226 |
| 2.49 | 6.2001 | 15.4382 | 1.57797 | 4.98999 | 1.35540 | 2.92011 | 6.29119 | .401606 |
| 2.50 | 6.2500 | 15.6250 | 1.58114 | 5.00000 | 1.35721 | 2.92402 | 6.29961 | .400000 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10\,n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10\,n}$ | $\sqrt[3]{100\,n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 2.51 | 6.3001 | 15.8133 | 1.58430 | 5.00999 | 1.35902 | 2.92791 | 6.30799 | .398406 |
| 2.52 | 6.3504 | 16.0030 | 1.58745 | 5.01996 | 1.36082 | 2.93179 | 6.31636 | .396825 |
| 2.53 | 6.4009 | 16.1943 | 1.59060 | 5.02991 | 1.36262 | 2.93567 | 6.32470 | .395257 |
| 2.54 | 6.4516 | 16.3871 | 1.59374 | 5.03984 | 1.36441 | 2.93953 | 6.33303 | .393701 |
| 2.55 | 6.5025 | 16.5814 | 1.59687 | 5.04975 | 1.36620 | 2.94338 | 6.34133 | .392157 |
| 2.56 | 6.5536 | 16.7772 | 1.60000 | 5.05964 | 1.36798 | 2.94723 | 6.34960 | .390625 |
| 2.57 | 6.6049 | 16.9746 | 1.60312 | 5.06952 | 1.36976 | 2.95106 | 6.35786 | .389105 |
| 2.58 | 6.6564 | 17.1735 | 1.60624 | 5.07937 | 1.37153 | 2.95488 | 6.36610 | .387597 |
| 2.59 | 6.7081 | 17.3740 | 1.60935 | 5.08920 | 1.37330 | 2.95869 | 6.37431 | .386100 |
| 2.60 | 6.7600 | 17.5760 | 1.61245 | 5.09902 | 1.37507 | 2.96250 | 6.38250 | .384615 |
| 2.61 | 6.8121 | 17.7796 | 1.61555 | 5.10882 | 1.37683 | 2.96629 | 6.39068 | .383142 |
| 2.62 | 6.8644 | 17.9847 | 1.61864 | 5.11859 | 1.37859 | 2.97007 | 6.39883 | .381679 |
| 2.63 | 6.9169 | 18.1914 | 1.62173 | 5.12835 | 1.38034 | 2.97385 | 6.40696 | .380228 |
| 2.64 | 6.9696 | 18.3997 | 1.62481 | 5.13809 | 1.38208 | 2.97761 | 6.41507 | .378788 |
| 2.65 | 7.0225 | 18.6096 | 1.62788 | 5.14782 | 1.38383 | 2.98137 | 6.42316 | .377359 |
| 2.66 | 7.0756 | 18.8211 | 1.63095 | 5.15752 | 1.38557 | 2.98511 | 6.43123 | .375940 |
| 2.67 | 7.1289 | 19.0342 | 1.63401 | 5.16720 | 1.38730 | 2.98885 | 6.43928 | .374532 |
| 2.68 | 7.1824 | 19.2488 | 1.63707 | 5.17687 | 1.38903 | 2.99257 | 6.44731 | .373134 |
| 2.69 | 7.2361 | 19.4651 | 1.64012 | 5.18652 | 1.39076 | 2.99629 | 6.45531 | .371747 |
| 2.70 | 7.2900 | 19.6830 | 1.64317 | 5.19615 | 1.39248 | 3.00000 | 6.46330 | .370370 |
| 2.71 | 7.3441 | 19.9025 | 1.64621 | 5.20577 | 1.39419 | 3.00370 | 6.47127 | .369004 |
| 2.72 | 7.3984 | 20.1236 | 1.64924 | 5.21536 | 1.39591 | 3.00739 | 6.47922 | .367647 |
| 2.73 | 7.4529 | 20.3464 | 1.65227 | 5.22494 | 1.39761 | 3.01107 | 6.48715 | .366300 |
| 2.74 | 7.5076 | 20.5708 | 1.65529 | 5.23450 | 1.39932 | 3.01474 | 6.49507 | .364964 |
| 2.75 | 7.5625 | 20.7969 | 1.65831 | 5.24404 | 1.40102 | 3.01841 | 6.50296 | .363636 |
| 2.76 | 7.6176 | 21.0246 | 1.66132 | 5.25357 | 1.40272 | 3.02206 | 6.51083 | .362319 |
| 2.77 | 7.6729 | 21.2539 | 1.66433 | 5.26308 | 1.40441 | 3.02571 | 6.51868 | .361011 |
| 2.78 | 7.7284 | 21.4850 | 1.66733 | 5.27257 | 1.40610 | 3.02934 | 6.52652 | .359712 |
| 2.79 | 7.7841 | 21.7176 | 1.67033 | 5.28205 | 1.40778 | 3.03297 | 6.53434 | .358423 |
| 2.80 | 7.8400 | 21.9520 | 1.67332 | 5.29150 | 1.40946 | 3.03659 | 6.54213 | .357142 |
| 2.81 | 7.8961 | 22.1880 | 1.67631 | 5.30094 | 1.41114 | 3.04020 | 6.54991 | .355872 |
| 2.82 | 7.9524 | 22.4258 | 1.67929 | 5.31037 | 1.41281 | 3.04380 | 6.55767 | .354610 |
| 2.83 | 8.0089 | 22.6652 | 1.68226 | 5.31977 | 1.41448 | 3.04740 | 6.56541 | .353357 |
| 2.84 | 8.0656 | 22.9063 | 1.68523 | 5.32917 | 1.41614 | 3.05098 | 6.57314 | .352113 |
| 2.85 | 8.1225 | 23.1491 | 1.68819 | 5.33854 | 1.41780 | 3.05456 | 6.58084 | .350877 |
| 2.86 | 8.1796 | 23.3937 | 1.69115 | 5.34790 | 1.41946 | 3.05813 | 6.58853 | .349650 |
| 2.87 | 8.2369 | 23.6399 | 1.69411 | 5.35724 | 1.42111 | 3.06169 | 6.59620 | .348432 |
| 2.88 | 8.2944 | 23.8879 | 1.69706 | 5.36656 | 1.42276 | 3.06524 | 6.60385 | .347222 |
| 2.89 | 8.3521 | 24.1376 | 1.70000 | 5.37587 | 1.42440 | 3.06878 | 6.61149 | .346021 |
| 2.90 | 8.4100 | 24.3890 | 1.70294 | 5.38516 | 1.42604 | 3.07232 | 6.61911 | .344828 |
| 2.91 | 8.4681 | 24.6422 | 1.70587 | 5.39444 | 1.42768 | 3.07585 | 6.62671 | .343643 |
| 2.92 | 8.5264 | 24.8971 | 1.70880 | 5.40370 | 1.42931 | 3.07936 | 6.63429 | .342466 |
| 2.93 | 8.5849 | 25.1538 | 1.71172 | 5.41295 | 1.43094 | 3.08287 | 6.64185 | .341297 |
| 2.94 | 8.6436 | 25.4122 | 1.71464 | 5.42218 | 1.43257 | 3.08638 | 6.64940 | .340136 |
| 2.95 | 8.7025 | 25.6724 | 1.71756 | 5.43139 | 1.43419 | 3.08987 | 6.65693 | .338983 |
| 2.96 | 8.7616 | 25.9343 | 1.72047 | 5.44059 | 1.43581 | 3.09336 | 6.66444 | .337838 |
| 2.97 | 8.8209 | 26.1981 | 1.72337 | 5.44977 | 1.43743 | 3.09684 | 6.67194 | .336700 |
| 2.98 | 8.8804 | 26.4636 | 1.72627 | 5.45894 | 1.43904 | 3.10031 | 6.67942 | .335571 |
| 2.99 | 8.9401 | 26.7309 | 1.72916 | 5.46809 | 1.44065 | 3.10378 | 6.68688 | .334448 |
| 3.00 | 9.0000 | 27.0000 | 1.73205 | 5.47723 | 1.44225 | 3.10723 | 6.69433 | .333333 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10\,n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10\,n}$ | $\sqrt[3]{100\,n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 3.01 | 9.0601 | 27.2709 | 1.73494 | 5.48635 | 1.44385 | 3.11068 | 6.70176 | .332226 |
| 3.02 | 9.1204 | 27.5436 | 1.73781 | 5.49545 | 1.44545 | 3.11412 | 6.70917 | .331126 |
| 3.03 | 9.1809 | 27.8181 | 1.74069 | 5.50454 | 1.44704 | 3.11755 | 6.71657 | .330033 |
| 3.04 | 9.2416 | 28.0945 | 1.74356 | 5.51362 | 1.44863 | 3.12098 | 6.72395 | .328947 |
| 3.05 | 9.3025 | 28.3726 | 1.74642 | 5.52268 | 1 45022 | 3.12440 | 6.73132 | .327869 |
| 3.06 | 9.3636 | 28.6526 | 1.74929 | 5.53173 | 1.45180 | 3.12781 | 6.73866 | .326797 |
| 3.07 | 9.4249 | 28.9344 | 1.75214 | 5.54076 | 1.45338 | 3.13121 | 6.74600 | .325733 |
| 3.08 | 9.4864 | 29.2181 | 1.75499 | 5.54977 | 1.45496 | 3.13461 | 6.75331 | .324675 |
| 3.09 | 9.5481 | 29.5036 | 1.75784 | 5.55878 | 1.45653 | 3.13800 | 6.76061 | .323625 |
| 3.10 | 9.6100 | 29.7910 | 1.76068 | 5.56776 | 1.45810 | 3.14138 | 6.76790 | .322581 |
| 3.11 | 9.6721 | 30.0802 | 1.76352 | 5.57674 | 1.45967 | 3.14475 | 6.77517 | .321543 |
| 3.12 | 9.7344 | 30.3713 | 1.76635 | 5.58570 | 1.46123 | 3.14812 | 6.78242 | .320513 |
| 3.13 | 9.7969 | 30.6643 | 1.76918 | 5.59464 | 1.46279 | 3.15148 | 6.78966 | .319489 |
| 3.14 | 9.8596 | 30.9591 | 1.77200 | 5.60357 | 1.46434 | 3.15484 | 6.79688 | .318471 |
| 3.15 | 9.9225 | 31.2559 | 1.77482 | 5.61249 | 1.46590 | 3.15818 | 6.80409 | .317460 |
| 3.16 | 9.9856 | 31.5545 | 1.77764 | 5.62139 | 1.46745 | 3.16152 | 6.81128 | .316456 |
| 3.17 | 10.0489 | 31.8550 | 1.78045 | 5.63028 | 1.46899 | 3.16485 | 6.81846 | .315457 |
| 3.18 | 10.1124 | 32.1574 | 1.78326 | 5.63915 | 1.47054 | 3.16817 | 6.82562 | .314465 |
| 3.19 | 10.1761 | 32.4618 | 1.78606 | 5.64801 | 1.47208 | 3.17149 | 6.83277 | .313480 |
| 3.20 | 10.2400 | 32.7680 | 1.78885 | 5.65685 | 1.47361 | 3.17480 | 6.83990 | .312500 |
| 3.21 | 10.3041 | 33.0762 | 1.79165 | 5.66569 | 1.47515 | 3.17811 | 6.84702 | .311527 |
| 3.22 | 10.3684 | 33.3862 | 1.79444 | 5.67450 | 1.47668 | 3.18140 | 6.85412 | .310559 |
| 3.23 | 10.4329 | 33.6983 | 1.79722 | 5.68331 | 1.47820 | 3.18469 | 6.86121 | .309598 |
| 3.24 | 10.4976 | 34.0122 | 1.80000 | 5.69210 | 1.47973 | 3.18798 | 6.86829 | .308642 |
| 3.25 | 10.5625 | 34.3281 | 1.80278 | 5.70088 | 1.48125 | 3.19125 | 6.87534 | .307692 |
| 3.26 | 10.6276 | 34.6460 | 1.80555 | 5.70964 | 1.48277 | 3.19452 | 6.88239 | .306749 |
| 3.27 | 10.6929 | 34.9658 | 1.80831 | 5.71839 | 1.48428 | 3.19779 | 6.88942 | .305810 |
| 3.28 | 10.7584 | 35.2876 | 1.81108 | 5.72713 | 1.48579 | 3.20104 | 6.89643 | .304878 |
| 3.29 | 10.8241 | 35.6129 | 1.81384 | 5.73585 | 1.48730 | 3.20429 | 6.90344 | .303951 |
| 3.30 | 10.8900 | 35.9370 | 1.81659 | 5.74456 | 1.48881 | 3.20753 | 6.91042 | .303030 |
| 3.31 | 10.9561 | 36.2647 | 1.81934 | 5.75326 | 1.49031 | 3.21077 | 6.91740 | .302115 |
| 3.32 | 11.0224 | 36.5944 | 1.82209 | 5.76194 | 1.49181 | 3.21400 | 6.92436 | .301205 |
| 3.33 | 11.0889 | 36.9260 | 1.82483 | 5.77062 | 1.49330 | 3.21723 | 6.93130 | .300300 |
| 3.34 | 11.1556 | 37.2597 | 1.82757 | 5.77927 | 1.49480 | 3.22044 | 6.93823 | .299401 |
| 3.35 | 11.2225 | 37.5954 | 1.83030 | 5.78792 | 1.49629 | 3.22365 | 6.94515 | .298508 |
| 3.36 | 11.2896 | 37.9331 | 1.83303 | 5.79655 | 1.49777 | 3.22686 | 6.95205 | .297619 |
| 3.37 | 11.3569 | 38.2728 | 1.83576 | 5.80517 | 1.49926 | 3.23005 | 6.95894 | .296736 |
| 3.38 | 11.4244 | 38.6145 | 1.83848 | 5.81378 | 1.50074 | 3.23325 | 6.96582 | .295858 |
| 3.39 | 11.4921 | 38.9582 | 1.84120 | 5.82237 | 1.50222 | 3.23643 | 6.97268 | .294985 |
| 3.40 | 11.5600 | 39.3040 | 1.84391 | 5.83095 | 1.50369 | 3.23961 | 6.97953 | .294118 |
| 3.41 | 11.6281 | 39.6518 | 1.84662 | 5.83952 | 1.50517 | 3.24278 | 6.98637 | .293255 |
| 3.42 | 11.6964 | 40.0017 | 1.84932 | 5.84808 | 1.50664 | 3.24595 | 6.99319 | .292398 |
| 3.43 | 11.7649 | 40.3536 | 1.85203 | 5.85662 | 1.50810 | 3.24911 | 7.00000 | .291545 |
| 3.44 | 11.8336 | 40.7076 | 1.85472 | 5.86515 | 1.50957 | 3.25227 | 7.00680 | .290698 |
| 3.45 | 11.9025 | 41.0636 | 1.85742 | 5.87367 | 1.51103 | 3.25542 | 7.01358 | .289855 |
| 3.46 | 11.9716 | 41.4217 | 1.86011 | 5.88218 | 1.51249 | 3.25856 | 7.02035 | .289017 |
| 3.47 | 12.0409 | 41.7819 | 1.86279 | 5.89067 | 1.51394 | 3.26169 | 7.02711 | .288184 |
| 3.48 | 12.1104 | 42.1442 | 1.86548 | 5.89915 | 1.51540 | 3.26482 | 7.03385 | .287356 |
| 3.49 | 12.1801 | 42.5085 | 1.86815 | 5.90762 | 1.51685 | 3.26795 | 7.04058 | .286533 |
| 3.50 | 12.2500 | 42.8750 | 1.87083 | 5.91608 | 1.51829 | 3.27107 | 7.04730 | .285714 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10n}$ | $\sqrt[3]{100n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 3.51 | 12.3201 | 43.2436 | 1.87350 | 5.92453 | 1.51974 | 3.27418 | 7.05400 | .284900 |
| 3.52 | 12.3904 | 43.6142 | 1.87617 | 5.93296 | 1.52118 | 3.27729 | 7.06070 | .284091 |
| 3.53 | 12.4609 | 43.9870 | 1.87883 | 5.94138 | 1.52262 | 3.28039 | 7.06738 | .283286 |
| 3.54 | 12.5316 | 44.3619 | 1.88149 | 5.94979 | 1.52406 | 3.28348 | 7.07404 | .282486 |
| 3.55 | 12.6025 | 44.7389 | 1.88414 | 5.95819 | 1.52549 | 3.28657 | 7.08070 | .281690 |
| 3.56 | 12.6736 | 45.1180 | 1.88680 | 5.96657 | 1.52692 | 3.28965 | 7.08734 | .280899 |
| 3.57 | 12.7449 | 45.4993 | 1.88944 | 5.97495 | 1.52835 | 3.29273 | 7.09397 | .280112 |
| 3.58 | 12.8164 | 45.8827 | 1.89209 | 5.98331 | 1.52978 | 3.29580 | 7.10059 | .279330 |
| 3.59 | 12.8881 | 46.2683 | 1.89473 | 5.99166 | 1.53120 | 3.29887 | 7.10719 | .278552 |
| 3.60 | 12.9600 | 46.6560 | 1.89737 | 6.00000 | 1.53262 | 3.30193 | 7.11379 | .277778 |
| 3.61 | 13.0321 | 47.0459 | 1.90000 | 6.00833 | 1.53404 | 3.30498 | 7.12037 | .277008 |
| 3.62 | 13.1044 | 47.4379 | 1.90263 | 6.01664 | 1.53545 | 3.30803 | 7.12694 | .276243 |
| 3.63 | 13.1769 | 47.8321 | 1.90526 | 6.02495 | 1.53686 | 3.31107 | 7.13349 | .275482 |
| 3.64 | 13.2496 | 48.2285 | 1.90788 | 6.03324 | 1.53827 | 3.31411 | 7.14004 | .274725 |
| 3.65 | 13.3225 | 48.6271 | 1.91050 | 6.04152 | 1.53968 | 3.31714 | 7.14657 | .273973 |
| 3.66 | 13.3956 | 49.0279 | 1.91311 | 6.04979 | 1.54109 | 3.32017 | 7.15309 | .273224 |
| 3.67 | 13.4689 | 49.4309 | 1.91572 | 6.05805 | 1.54249 | 3.32319 | 7.15960 | .272480 |
| 3.68 | 13.5424 | 49.8360 | 1.91833 | 6.06630 | 1.54389 | 3.32621 | 7.16610 | .271739 |
| 3.69 | 13.6161 | 50.2434 | 1.92094 | 6.07454 | 1.54529 | 3.32922 | 7.17258 | .271003 |
| 3.70 | 13.6900 | 50.6530 | 1.92354 | 6.08276 | 1.54668 | 3.33222 | 7.17905 | .270270 |
| 3.71 | 13.7641 | 51.0648 | 1.92614 | 6.09098 | 1.54807 | 3.33522 | 7.18552 | .269542 |
| 3.72 | 13.8384 | 51.4788 | 1.92873 | 6.09918 | 1.54946 | 3.33822 | 7.19197 | .268817 |
| 3.73 | 13.9129 | 51.8951 | 1.93132 | 6.10737 | 1.55085 | 3.34120 | 7.19841 | .268097 |
| 3.74 | 13.9876 | 52.3136 | 1.93391 | 6.11555 | 1.55223 | 3.34419 | 7.20483 | .267380 |
| 3.75 | 14.0625 | 52.7344 | 1.93649 | 6.12372 | 1.55362 | 3.34716 | 7.21125 | .266667 |
| 3.76 | 14.1376 | 53.1574 | 1.93907 | 6.13188 | 1.55500 | 3.35014 | 7.21765 | .265957 |
| 3.77 | 14.2129 | 53.5826 | 1.94165 | 6.14003 | 1.55637 | 3.35310 | 7.22405 | .265252 |
| 3.78 | 14.2884 | 54.0102 | 1.94422 | 6.14817 | 1.55775 | 3.35607 | 7.23043 | .264550 |
| 3.79 | 14.3641 | 54.4399 | 1.94679 | 6.15630 | 1.55912 | 3.35902 | 7.23680 | .263852 |
| 3.80 | 14.4400 | 54.8720 | 1.94936 | 6.16441 | 1.56049 | 3.36198 | 7.24316 | .263158 |
| 3.81 | 14.5161 | 55.3063 | 1.95192 | 6.17252 | 1.56186 | 3.36492 | 7.24950 | .262467 |
| 3.82 | 14.5924 | 55.7430 | 1.95448 | 6.18061 | 1.56322 | 3.36786 | 7.25584 | .261780 |
| 3.83 | 14.6689 | 56.1819 | 1.95704 | 6.18870 | 1.56459 | 3.37080 | 7.26217 | .261097 |
| 3.84 | 14.7456 | 56.6231 | 1.95959 | 6.19677 | 1.56595 | 3.37373 | 7.26848 | .260417 |
| 3.85 | 14.8225 | 57.0666 | 1.96214 | 6.20484 | 1.56731 | 3.37666 | 7.27479 | .259740 |
| 3.86 | 14.8996 | 57.5125 | 1.96469 | 6.21289 | 1.56866 | 3.37958 | 7.28108 | .259067 |
| 3.87 | 14.9769 | 57.9606 | 1.96723 | 6.22093 | 1.57001 | 3.38249 | 7.28736 | .258398 |
| 3.88 | 15.0544 | 58.4111 | 1.96977 | 6.22896 | 1.57137 | 3.38540 | 7.29363 | .257732 |
| 3.89 | 15.1321 | 58.8639 | 1.97231 | 6.23699 | 1.57271 | 3.38831 | 7.29989 | .257069 |
| 3.90 | 15.2100 | 59.3190 | 1.97484 | 6.24500 | 1.57406 | 3.39121 | 7.30614 | .256410 |
| 3.91 | 15.2881 | 59.7765 | 1.97737 | 6.25300 | 1.57541 | 3.39411 | 7.31238 | .255755 |
| 3.92 | 15.3664 | 60.2363 | 1.97990 | 6.26099 | 1.57675 | 3.39700 | 7.31861 | .255102 |
| 3.93 | 15.4449 | 60.6985 | 1.98242 | 6.26897 | 1.57809 | 3.39988 | 7.32483 | .254453 |
| 3.94 | 15.5236 | 61.1630 | 1.98494 | 6.27694 | 1.57942 | 3.40277 | 7.33104 | .253807 |
| 3.95 | 15.6025 | 61.6299 | 1.98746 | 6.28490 | 1.58076 | 3.40564 | 7.33723 | .253165 |
| 3.96 | 15.6816 | 62.0991 | 1.98997 | 6.29285 | 1.58209 | 3.40851 | 7.34342 | .252525 |
| 3.97 | 15.7609 | 62.5708 | 1.99249 | 6.30079 | 1.58342 | 3.41138 | 7.34960 | .251889 |
| 3.98 | 15.8404 | 63.0448 | 1.99499 | 6.30872 | 1.58475 | 3.41424 | 7.35576 | .251256 |
| 3.99 | 15.9201 | 63.5212 | 1.99750 | 6.31664 | 1.58608 | 3.41710 | 7.36192 | .250627 |
| 4.00 | 16.0000 | 64.0000 | 2.00000 | 6.32456 | 1.58740 | 3.41995 | 7.36806 | .250000 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10n}$ | $\sqrt[3]{100n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 4.01 | 16.0801 | 64.4812 | 2.00250 | 6.33246 | 1.58872 | 3.42280 | 7.37420 | .249377 |
| 4.02 | 16.1604 | 64.9648 | 2.00499 | 6.34035 | 1.59004 | 3.42564 | 7.38032 | .248756 |
| 4.03 | 16.2409 | 65.4508 | 2.00749 | 6.34823 | 1.59136 | 3.42848 | 7.38644 | .248139 |
| 4.04 | 16.3216 | 65.9393 | 2.00998 | 6.35610 | 1.59267 | 3.43131 | 7.39254 | .247525 |
| 4.05 | 16.4025 | 66.4301 | 2.01246 | 6.36396 | 1.59399 | 3.43414 | 7.39864 | .246914 |
| 4.06 | 16.4836 | 66.9234 | 2.01494 | 6.37181 | 1.59530 | 3.43697 | 7.40472 | .246305 |
| 4.07 | 16.5649 | 67.4191 | 2.01742 | 6.37966 | 1.59661 | 3.43979 | 7.41080 | .245700 |
| 4.08 | 16.6464 | 67.9173 | 2.01990 | 6.38749 | 1.59791 | 3.44260 | 7.41686 | .245098 |
| 4.09 | 16.7281 | 68.4179 | 2.02237 | 6.39531 | 1.59922 | 3.44541 | 7.42291 | .244499 |
| 4.10 | 16.8100 | 68.9210 | 2.02485 | 6.40312 | 1.60052 | 3.44822 | 7.42896 | .243902 |
| 4.11 | 16.8921 | 69.4265 | 2.02731 | 6.41093 | 1.60182 | 3.45102 | 7.43499 | .243309 |
| 4.12 | 16.9744 | 69.9345 | 2.02978 | 6.41872 | 1.60312 | 3.45382 | 7.44102 | .242718 |
| 4.13 | 17.0569 | 70.4450 | 2.03224 | 6.42651 | 1.60441 | 3.45661 | 7.44703 | .242131 |
| 4.14 | 17.1396 | 70.9579 | 2.03470 | 6.43428 | 1.60571 | 3.45939 | 7.45304 | .241546 |
| 4.15 | 17.2225 | 71.4734 | 2.03715 | 6.44205 | 1.60700 | 3.46218 | 7.45904 | .240964 |
| 4.16 | 17.3056 | 71.9913 | 2.03961 | 6.44981 | 1.60829 | 3.46496 | 7.46502 | .240385 |
| 4.17 | 17.3889 | 72.5117 | 2.04206 | 6.45755 | 1.60958 | 3.46773 | 7.47100 | .239808 |
| 4.18 | 17.4724 | 73.0346 | 2.04450 | 6.46529 | 1.61086 | 3.47050 | 7.47697 | .239234 |
| 4.19 | 17.5561 | 73.5601 | 2.04695 | 6.47302 | 1.61215 | 3.47327 | 7.48292 | .238664 |
| 4.20 | 17.6400 | 74.0880 | 2.04939 | 6.48074 | 1.61343 | 3.47603 | 7.48887 | .238095 |
| 4.21 | 17.7241 | 74.6185 | 2.05183 | 6.48845 | 1.61471 | 3.47878 | 7.49481 | .237530 |
| 4.22 | 17.8084 | 75.1514 | 2.05426 | 6.49615 | 1.61599 | 3.48154 | 7.50074 | .236967 |
| 4.23 | 17.8929 | 75.6870 | 2.05670 | 6.50385 | 1.61726 | 3.48428 | 7.50666 | .236407 |
| 4.24 | 17.9776 | 76.2250 | 2.05913 | 6.51153 | 1.61853 | 3.48703 | 7.51257 | .235849 |
| 4.25 | 18.0625 | 76.7656 | 2.06155 | 6.51920 | 1.61981 | 3.48977 | 7.51847 | .235294 |
| 4.26 | 18.1476 | 77.3088 | 2.06398 | 6.52687 | 1.62108 | 3.49250 | 7.52437 | .234742 |
| 4.27 | 18.2329 | 77.8545 | 2.06640 | 6.53452 | 1.62234 | 3.49523 | 7.53025 | .234192 |
| 4.28 | 18.3184 | 78.4028 | 2.06882 | 6.54217 | 1.62361 | 3.49796 | 7.53612 | .233645 |
| 4.29 | 18.4041 | 78.9536 | 2.07123 | 6.54981 | 1.62487 | 3.50068 | 7.54199 | .233100 |
| 4.30 | 18.4900 | 79.5070 | 2.07364 | 6.55744 | 1.62613 | 3.50340 | 7.54784 | .232558 |
| 4.31 | 18.5761 | 80.0630 | 2.07605 | 6.56506 | 1.62739 | 3.50611 | 7.55369 | .232019 |
| 4.32 | 18.6624 | 80.6216 | 2.07846 | 6.57267 | 1.62865 | 3.50882 | 7.55953 | .231482 |
| 4.33 | 18.7489 | 81.1827 | 2.08087 | 6.58027 | 1.62991 | 3.51153 | 7.56535 | .230947 |
| 4.34 | 18.8356 | 81.7465 | 2.08327 | 6.58787 | 1.63116 | 3.51423 | 7.57117 | .230415 |
| 4.35 | 18.9225 | 82.3129 | 2.08567 | 6.59545 | 1.63241 | 3.51692 | 7.57698 | .229885 |
| 4.36 | 19.0096 | 82.8819 | 2.08806 | 6.60303 | 1.63366 | 3.51962 | 7.58279 | .229358 |
| 4.37 | 19.0969 | 83.4535 | 2.09045 | 6.61060 | 1.63491 | 3.52231 | 7.58858 | .228833 |
| 4.38 | 19.1844 | 84.0277 | 2.09284 | 6.61816 | 1.63616 | 3.52499 | 7.59436 | .228311 |
| 4.39 | 19.2721 | 84.6045 | 2.09523 | 6.62571 | 1.63740 | 3.52767 | 7.60014 | .227790 |
| 4.40 | 19.3600 | 85.1840 | 2.09762 | 6.63325 | 1.63864 | 3.53035 | 7.60590 | .227273 |
| 4.41 | 19.4481 | 85.7661 | 2.10000 | 6.64078 | 1.63988 | 3.53302 | 7.61166 | .226757 |
| 4.42 | 19.5364 | 86.3509 | 2.10238 | 6.64831 | 1.64112 | 3.53569 | 7.61741 | .226244 |
| 4.43 | 19.6249 | 86.9383 | 2.10476 | 6.65582 | 1.64236 | 3.53835 | 7.62315 | .225734 |
| 4.44 | 19.7136 | 87.5284 | 2.10713 | 6.66333 | 1.64359 | 3.54101 | 7.62888 | .225225 |
| 4.45 | 19.8025 | 88.1211 | 2.10950 | 6.67083 | 1.64483 | 3.54367 | 7.63461 | .224719 |
| 4.46 | 19.8916 | 88.7165 | 2.11187 | 6.67832 | 1.64606 | 3.54632 | 7.64032 | .224215 |
| 4.47 | 19.9809 | 89.3146 | 2.11424 | 6.68581 | 1.64729 | 3.54897 | 7.64603 | .223714 |
| 4.48 | 20.0704 | 89.9154 | 2.11660 | 6.69328 | 1.64851 | 3.55162 | 7.65172 | .223214 |
| 4.49 | 20.1601 | 90.5188 | 2.11896 | 6.70075 | 1.64974 | 3.55426 | 7.65741 | .222717 |
| 4.50 | 20.2500 | 91.1250 | 2.12132 | 6.70820 | 1.65096 | 3.55689 | 7.66309 | .222222 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10\,n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10\,n}$ | $\sqrt[3]{100\,n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 4.51 | 20.3401 | 91.7339 | 2.12368 | 6.71565 | 1.65219 | 3.55953 | 7.66877 | .221730 |
| 4.52 | 20.4304 | 92.3454 | 2.12603 | 6.72309 | 1.65341 | 3.56215 | 7.67443 | .221239 |
| 4.53 | 20.5209 | 92.9597 | 2.12838 | 6.73053 | 1.65462 | 3.56478 | 7.68009 | .220751 |
| 4.54 | 20.6116 | 93.5767 | 2.13073 | 6.73795 | 1.65584 | 3.56740 | 7.68573 | .220264 |
| 4.55 | 20.7025 | 94.1964 | 2.13307 | 6.74537 | 1.65706 | 3.57002 | 7.69137 | .219780 |
| 4.56 | 20.7936 | 94.8188 | 2.13542 | 6.75278 | 1.65827 | 3.57263 | 7.69700 | .219298 |
| 4.57 | 20.8849 | 95.4440 | 2.13776 | 6.76018 | 1.65948 | 3.57524 | 7.70262 | .218818 |
| 4.58 | 20.9764 | 96.0719 | 2.14009 | 6.76757 | 1.66069 | 3.57785 | 7.70824 | .218341 |
| 4.59 | 21.0681 | 96.7026 | 2.14243 | 6.77495 | 1.66190 | 3.58045 | 7.71384 | .217865 |
| 4.60 | 21.1600 | 97.3360 | 2.14476 | 6.78233 | 1.66310 | 3.58305 | 7.71944 | .217391 |
| 4.61 | 21.2521 | 97.9722 | 2.14709 | 6.78970 | 1.66431 | 3.58564 | 7.72503 | .216920 |
| 4.62 | 21.3444 | 98.6111 | 2.14942 | 6.79706 | 1.66551 | 3.58823 | 7.73061 | .216450 |
| 4.63 | 21.4369 | 99.2528 | 2.15174 | 6.80441 | 1.66671 | 3.59082 | 7.73619 | .215983 |
| 4.64 | 21.5296 | 99.8973 | 2.15407 | 6.81175 | 1.66791 | 3.59340 | 7.74175 | .215517 |
| 4.65 | 21.6225 | 100.545 | 2.15639 | 6.81909 | 1.66911 | 3.59598 | 7.74731 | .215054 |
| 4.66 | 21.7156 | 101.195 | 2.15870 | 6.82642 | 1.67030 | 3.59856 | 7.75286 | .214592 |
| 4.67 | 21.8089 | 101.848 | 2.16102 | 6.83374 | 1.67150 | 3.60113 | 7.75840 | .214133 |
| 4.68 | 21.9024 | 102.503 | 2.16333 | 6.84105 | 1.67269 | 3.60370 | 7.76394 | .213675 |
| 4.69 | 21.9961 | 103.162 | 2.16564 | 6.84836 | 1.67388 | 3.60626 | 7.76946 | .213220 |
| 4.70 | 22.0900 | 103.823 | 2.16795 | 6.85565 | 1.67507 | 3.60883 | 7.77498 | .212766 |
| 4.71 | 22.1841 | 104.487 | 2.17025 | 6.86294 | 1.67626 | 3.61138 | 7.78049 | .212314 |
| 4.72 | 22.2784 | 105.154 | 2.17256 | 6.87023 | 1.67744 | 3.61394 | 7.78599 | .211864 |
| 4.73 | 22.3729 | 105.824 | 2.17486 | 6.87750 | 1.67863 | 3.61649 | 7.79149 | .211417 |
| 4.74 | 22.4676 | 106.496 | 2.17715 | 6.88477 | 1.67981 | 3.61904 | 7.79697 | .210971 |
| 4.75 | 22.5625 | 107.172 | 2.17945 | 6.89202 | 1.68099 | 3.62158 | 7.80245 | .210526 |
| 4.76 | 22.6576 | 107.850 | 2.18174 | 6.89928 | 1.68217 | 3.62412 | 7.80793 | .210084 |
| 4.77 | 22.7529 | 108.531 | 2.18403 | 6.90652 | 1.68334 | 3.62665 | 7.81339 | .209644 |
| 4.78 | 22.8484 | 109.215 | 2.18632 | 6.91375 | 1.68452 | 3.62919 | 7.81885 | .209205 |
| 4.79 | 22.9441 | 109.902 | 2.18861 | 6.92098 | 1.68569 | 3.63171 | 7.82429 | .208768 |
| 4.80 | 23.0400 | 110.592 | 2.19089 | 6.92820 | 1.68687 | 3.63424 | 7.82974 | .208333 |
| 4.81 | 23.1361 | 111.285 | 2.19317 | 6.93542 | 1.68804 | 3.63676 | 7.83517 | .207900 |
| 4.82 | 23.2324 | 111.980 | 2.19545 | 6.94262 | 1.68920 | 3.63928 | 7.84059 | .207469 |
| 4.83 | 23.3289 | 112.679 | 2.19773 | 6.94982 | 1.69037 | 3.64180 | 7.84601 | .207039 |
| 4.84 | 23.4256 | 113.380 | 2.20000 | 6.95701 | 1.69154 | 3.64431 | 7.85142 | .206612 |
| 4.85 | 23.5225 | 114.084 | 2.20227 | 6.96419 | 1.69270 | 3.64682 | 7.85683 | .206186 |
| 4.86 | 23.6196 | 114.791 | 2.20454 | 6.97137 | 1.69386 | 3.64932 | 7.86222 | .205761 |
| 4.87 | 23.7169 | 115.501 | 2.20681 | 6.97854 | 1.69503 | 3.65182 | 7.86761 | .205339 |
| 4.88 | 23.8144 | 116.214 | 2.20907 | 6.98570 | 1.69619 | 3.65432 | 7.87299 | .204918 |
| 4.89 | 23.9121 | 116.930 | 2.21133 | 6.99285 | 1.69734 | 3.65682 | 7.87837 | .204499 |
| 4.90 | 24.0100 | 117.649 | 2.21359 | 7.00000 | 1.69850 | 3.65931 | 7.88374 | .204082 |
| 4.91 | 24.1081 | 118.371 | 2.21585 | 7.00714 | 1.69965 | 3.66179 | 7.88909 | .203666 |
| 4.92 | 24.2064 | 119.095 | 2.21811 | 7.01427 | 1.70081 | 3.66428 | 7.89445 | .203252 |
| 4.93 | 24.3049 | 119.823 | 2.22036 | 7.02140 | 1.70196 | 3.66676 | 7.89979 | .202840 |
| 4.94 | 24.4036 | 120.554 | 2.22261 | 7.02851 | 1.70311 | 3.66924 | 7.90513 | .202429 |
| 4.95 | 24.5025 | 121.287 | 2.22486 | 7.03562 | 1.70426 | 3.67171 | 7.91046 | .202020 |
| 4.96 | 24.6016 | 122.024 | 2.22711 | 7.04273 | 1.70540 | 3.67418 | 7.91578 | .201613 |
| 4.97 | 24.7009 | 122.763 | 2.22935 | 7.04982 | 1.70655 | 3.67665 | 7.92110 | .201207 |
| 4.98 | 24.8004 | 123.506 | 2.23159 | 7.05691 | 1.70769 | 3.67911 | 7.92641 | .200803 |
| 4.99 | 24.9001 | 124.251 | 2.23383 | 7.06399 | 1.70884 | 3.68157 | 7.93171 | .200401 |
| 5.00 | 25.0000 | 125.000 | 2.23607 | 7.07107 | 1.70998 | 3.68403 | 7.93701 | .200000 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10\,n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10\,n}$ | $\sqrt[3]{100\,n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 5.01 | 25.1001 | 125.752 | 2.23830 | 7.07814 | 1.71112 | 3.68649 | 7.94229 | .199601 |
| 5.02 | 25.2004 | 126.506 | 2.24054 | 7.08520 | 1.71225 | 3.68894 | 7.94757 | .199203 |
| 5.03 | 25.3009 | 127.264 | 2.24277 | 7.09225 | 1.71339 | 3.69138 | 7.95285 | .198807 |
| 5.04 | 25.4016 | 128.024 | 2.24499 | 7.09930 | 1.71452 | 3.69383 | 7.95811 | .198413 |
| 5.05 | 25.5025 | 128.788 | 2.24722 | 7.10634 | 1.71566 | 3.69627 | 7.96337 | .198020 |
| 5.06 | 25.6036 | 129.554 | 2.24944 | 7.11337 | 1.71679 | 3.69871 | 7.96863 | .197629 |
| 5.07 | 25.7049 | 130.324 | 2.25167 | 7.12039 | 1.71792 | 3.70114 | 7.97387 | .197239 |
| 5.08 | 25.8064 | 131.097 | 2.25389 | 7.12741 | 1.71905 | 3.70358 | 7.97911 | .196850 |
| 5.09 | 25.9081 | 131.872 | 2.25610 | 7.13442 | 1.72017 | 3.70600 | 7.98434 | .196464 |
| 5.10 | 26.0100 | 132.651 | 2.25832 | 7.14143 | 1.72130 | 3.70843 | 7.98957 | .196078 |
| 5.11 | 26.1121 | 133.433 | 2.26053 | 7.14843 | 1.72242 | 3.71085 | 7.99479 | .195695 |
| 5.12 | 26.2144 | 134.218 | 2.26274 | 7.15542 | 1.72355 | 3.71327 | 8.00000 | .195313 |
| 5.13 | 26.3169 | 135.006 | 2.26495 | 7.16240 | 1.72467 | 3.71566 | 8.00520 | .194932 |
| 5.14 | 26.4196 | 135.797 | 2.26716 | 7.16938 | 1.72579 | 3.71810 | 8.01040 | .194553 |
| 5.15 | 26.5225 | 136.591 | 2.26936 | 7.17635 | 1.72691 | 3.72051 | 8.01559 | .194175 |
| 5.16 | 26.6256 | 137.388 | 2.27156 | 7.18331 | 1.72802 | 3.72292 | 8.02078 | .193798 |
| 5.17 | 26.7289 | 138.188 | 2.27376 | 7.19027 | 1.72914 | 3.72532 | 8.02596 | .193424 |
| 5.18 | 26.8324 | 138.992 | 2.27596 | 7.19722 | 1.73025 | 3.72772 | 8.03113 | .193050 |
| 5.19 | 26.9361 | 139.798 | 2.27816 | 7.20417 | 1.73137 | 3.73012 | 8.03629 | .192678 |
| 5.20 | 27.0400 | 140.608 | 2.28035 | 7.21110 | 1.73248 | 3.73251 | 8.04145 | .192308 |
| 5.21 | 27.1441 | 141.421 | 2.28254 | 7.21803 | 1.73359 | 3.73490 | 8.04660 | .191939 |
| 5.22 | 27.2484 | 142.237 | 2.28473 | 7.22496 | 1.73470 | 3.73729 | 8.05175 | .191571 |
| 5.23 | 27.3529 | 143.056 | 2.28692 | 7.23187 | 1.73580 | 3.73968 | 8.05689 | .191205 |
| 5.24 | 27.4576 | 143.878 | 2.28910 | 7.23878 | 1.73691 | 3.74206 | 8.06202 | .190840 |
| 5.25 | 27.5625 | 144.703 | 2.29129 | 7.24569 | 1.73801 | 3.74443 | 8.06714 | .190476 |
| 5.26 | 27.6676 | 145.532 | 2.29347 | 7.25259 | 1.73912 | 3.74681 | 8.07226 | .190114 |
| 5.27 | 27.7729 | 146.363 | 2.29565 | 7.25948 | 1.74022 | 3.74918 | 8.07737 | .189753 |
| 5.28 | 27.8784 | 147.198 | 2.29783 | 7.26636 | 1.74132 | 3.75158 | 8.08248 | .189394 |
| 5.29 | 27.9841 | 148.036 | 2.30000 | 7.27324 | 1.74242 | 3.75392 | 8.08758 | .189036 |
| 5.30 | 28.0900 | 148.877 | 2.30217 | 7.28011 | 1.74351 | 3.75629 | 8.09267 | .188679 |
| 5.31 | 28.1961 | 149.721 | 2.30434 | 7.28697 | 1.74461 | 3.75865 | 8.09776 | .188324 |
| 5.32 | 28.3024 | 150.569 | 2.30651 | 7.29383 | 1.74570 | 3.76100 | 8.10284 | .187970 |
| 5.33 | 28.4089 | 151.419 | 2.30868 | 7.30068 | 1.74680 | 3.76336 | 8.10791 | .187617 |
| 5.34 | 28.5156 | 152.273 | 2.31084 | 7.30753 | 1.74789 | 3.76571 | 8.11298 | .187266 |
| 5.35 | 28.6225 | 153.130 | 2.31301 | 7.31437 | 1.74898 | 3.76806 | 8.11804 | .186916 |
| 5.36 | 28.7296 | 153.991 | 2.31517 | 7.32120 | 1.75007 | 3.77041 | 8.12310 | .186567 |
| 5.37 | 28.8369 | 154.854 | 2.31733 | 7.32803 | 1.75116 | 3.77275 | 8.12814 | .186220 |
| 5.38 | 28.9444 | 155.721 | 2.31948 | 7.33485 | 1.75224 | 3.77509 | 8.13319 | .185874 |
| 5.39 | 29.0521 | 156.591 | 2.32164 | 7.34166 | 1.75333 | 3.77740 | 8.13822 | .185529 |
| 5.40 | 29.1600 | 157.464 | 2.32379 | 7.34847 | 1.75441 | 3.77976 | 8.14325 | .185185 |
| 5.41 | 29.2681 | 158.340 | 2.32594 | 7.35527 | 1.75549 | 3.78210 | 8.14828 | .184843 |
| 5.42 | 29.3764 | 159.220 | 2.32809 | 7.36206 | 1.75657 | 3.78442 | 8.15329 | .184502 |
| 5.43 | 29.4849 | 160.103 | 2.33024 | 7.36885 | 1.75765 | 3.78675 | 8.15831 | .184162 |
| 5.44 | 29.5936 | 160.989 | 2.33238 | 7.37564 | 1.75873 | 3.78907 | 8.16331 | .183824 |
| 5.45 | 29.7025 | 161.879 | 2.33452 | 7.38241 | 1.75981 | 3.79139 | 8.16831 | .183486 |
| 5.46 | 29.8116 | 162.771 | 2.33666 | 7.38918 | 1.76088 | 3.79371 | 8.17330 | .183150 |
| 5.47 | 29.9209 | 163.667 | 2.33880 | 7.39594 | 1.76196 | 3.79603 | 8.17829 | .182815 |
| 5.48 | 30.0304 | 164.567 | 2.34094 | 7.40270 | 1.76303 | 3.79834 | 8.18327 | .182482 |
| 5.49 | 30.1401 | 165.469 | 2.34307 | 7.40945 | 1.76410 | 3.80065 | 8.18824 | .182149 |
| 5.50 | 30.2500 | 166.375 | 2.34521 | 7.41620 | 1.76517 | 3.80295 | 8.19321 | .181818 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10\,n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10\,n}$ | $\sqrt[3]{100\,n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 5.51 | 30.3601 | 167.284 | 2.34734 | 7.42294 | 1.76624 | 3.80526 | 8.19818 | .181488 |
| 5.52 | 30.4704 | 168.197 | 2.34947 | 7.42967 | 1.76731 | 3.80756 | 8.20313 | .181159 |
| 5.53 | 30.5809 | 169.112 | 2.35160 | 7.43640 | 1.76838 | 3.80986 | 8.20808 | .180832 |
| 5.54 | 30.6916 | 170.031 | 2.35372 | 7.44312 | 1.76944 | 3.80115 | 8.21303 | .180505 |
| 5.55 | 30.8025 | 170.954 | 2.35584 | 7.44983 | 1.77051 | 3.81444 | 8.21797 | .180180 |
| 5.56 | 30.9136 | 171.880 | 2.35797 | 7.45654 | 1.77157 | 3.81673 | 8.22290 | .179856 |
| 5.57 | 31.0249 | 172.809 | 2.36008 | 7.46324 | 1.77263 | 3.81902 | 8.22783 | .179533 |
| 5.58 | 31.1364 | 173.741 | 2.36220 | 7.46994 | 1.77369 | 3.82130 | 8.23275 | .179212 |
| 5.59 | 31.2481 | 174.677 | 2.36432 | 7.47663 | 1.77475 | 3.82358 | 8.23766 | .178891 |
| 5.60 | 31.3600 | 175.616 | 2.36643 | 7.48331 | 1.77581 | 3.82586 | 8.24257 | .178571 |
| 5.61 | 31.4721 | 176.558 | 2.36854 | 7.48999 | 1.77686 | 3.82814 | 8.24747 | .178253 |
| 5.62 | 31.5844 | 177.504 | 2.37065 | 7.49667 | 1.77792 | 3.83041 | 8.25237 | .177936 |
| 5.63 | 31.6969 | 178.454 | 2.37276 | 7.50333 | 1.77897 | 3.83268 | 8.25726 | .177620 |
| 5.64 | 31.8096 | 179.406 | 2.37487 | 7.50999 | 1.78003 | 3.83495 | 8.26215 | .177305 |
| 5.65 | 31.9225 | 180.362 | 2.37697 | 7.51665 | 1.78108 | 3.83721 | 8.26703 | .176991 |
| 5.66 | 32.0356 | 181.321 | 2.37908 | 7.52330 | 1.78213 | 3.83948 | 8.27190 | .176678 |
| 5.67 | 32.1489 | 182.284 | 2.38118 | 7.52994 | 1.78318 | 3.84174 | 8.27677 | .176367 |
| 5.68 | 32.2624 | 183.250 | 2.38328 | 7.53658 | 1.78422 | 3.84400 | 8.28164 | .176056 |
| 5.69 | 32.3761 | 184.220 | 2.38537 | 7.54321 | 1.78527 | 3.84625 | 8.28649 | .175747 |
| 5.70 | 32.4900 | 185.193 | 2.38747 | 7.54983 | 1.78632 | 3.84850 | 8.29134 | .175439 |
| 5.71 | 32.6041 | 186.169 | 2.38956 | 7.55645 | 1.78736 | 3.85075 | 8.29619 | .175131 |
| 5.72 | 32.7184 | 187.149 | 2.39165 | 7.56307 | 1.78840 | 3.85300 | 8.30103 | .174825 |
| 5.73 | 32.8329 | 188.133 | 2.39374 | 7.56968 | 1.78944 | 3.85524 | 8.30587 | .174520 |
| 5.74 | 32.9476 | 189.119 | 2.39583 | 7.57628 | 1.79048 | 3.85748 | 8.31069 | .174216 |
| 5.75 | 33.0625 | 190.109 | 2.39792 | 7.58288 | 1.79152 | 3.85972 | 8.31552 | .173913 |
| 5.76 | 33.1776 | 191.103 | 2.40000 | 7.58947 | 1.79256 | 3.86196 | 8.32034 | .173611 |
| 5.77 | 33.2929 | 192.100 | 2.40208 | 7.59605 | 1.79360 | 3.86419 | 8.32515 | .173310 |
| 5.78 | 33.4084 | 193.101 | 2.40416 | 7.60263 | 1.79463 | 3.86642 | 8.32995 | .173010 |
| 5.79 | 33.5241 | 194.105 | 2.40624 | 7.60920 | 1.79567 | 3.86865 | 8.33476 | .172712 |
| 5.80 | 33.6400 | 195.112 | 2.40832 | 7.61577 | 1.79670 | 3.87088 | 8.33955 | .172414 |
| 5.81 | 33.7561 | 196.123 | 2.41039 | 7.62234 | 1.79773 | 3.87310 | 8.34434 | .172117 |
| 5.82 | 33.8724 | 197.137 | 2.41247 | 7.62889 | 1.79876 | 3.87532 | 8.34913 | .171821 |
| 5.83 | 33.9889 | 198.155 | 2.41454 | 7.63544 | 1.79979 | 3.87754 | 8.35390 | .171527 |
| 5.84 | 34.1056 | 199.177 | 2.41661 | 7.64199 | 1.80082 | 3.87975 | 8.35868 | .171233 |
| 5.85 | 34.2225 | 200.202 | 2.41868 | 7.64853 | 1.80185 | 3.88197 | 8.36345 | .170940 |
| 5.86 | 34.3396 | 201.230 | 2.42074 | 7.65506 | 1.80288 | 3.88418 | 8.36821 | .170649 |
| 5.87 | 34.4569 | 202.262 | 2.42281 | 7.66159 | 1.80390 | 3.88639 | 8.37297 | .170358 |
| 5.88 | 34.5744 | 203.297 | 2.42487 | 7.66812 | 1.80492 | 3.88859 | 8.37772 | .170068 |
| 5.89 | 34.6921 | 204.336 | 2.42693 | 7.67463 | 1.80595 | 3.89082 | 8.38247 | .169779 |
| 5.90 | 34.8100 | 205.379 | 2.42899 | 7.68115 | 1.80697 | 3.89300 | 8.38721 | .169492 |
| 5.91 | 34.9281 | 206.425 | 2.43105 | 7.68765 | 1.80799 | 3.89520 | 8.39194 | .169205 |
| 5.92 | 35.0464 | 207.475 | 2.43311 | 7.69415 | 1.80901 | 3.89739 | 8.39667 | .168919 |
| 5.93 | 35.1649 | 208.528 | 2.43516 | 7.70065 | 1.81003 | 3.89958 | 8.40140 | .168634 |
| 5.94 | 35.2836 | 209.585 | 2.43721 | 7.70714 | 1.81104 | 3.90177 | 8.40612 | .168350 |
| 5.95 | 35.4025 | 210.645 | 2.43926 | 7.71362 | 1.81206 | 3.90396 | 8.41083 | .168067 |
| 5.96 | 35.5216 | 211.709 | 2.44131 | 7.72010 | 1.81307 | 3.90615 | 8.41554 | .167785 |
| 5.97 | 35.6409 | 212.776 | 2.44336 | 7.72658 | 1.81409 | 3.90833 | 8.42025 | .167504 |
| 5.98 | 35.7604 | 213.847 | 2.44540 | 7.73305 | 1.81510 | 3.91051 | 8.42494 | .167224 |
| 5.99 | 35.8801 | 214.922 | 2.44745 | 7.73951 | 1.81611 | 3.91269 | 8.42964 | .166945 |
| 6.00 | 36.0000 | 216.000 | 2.44949 | 7.74597 | 1.81712 | 3.91487 | 8.43433 | .166667 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10\,n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10\,n}$ | $\sqrt[3]{100\,n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 6.01 | 36.1201 | 217.082 | 2.45153 | 7.75242 | 1.81813 | 3.91704 | 8.43901 | .166389 |
| 6.02 | 36.2404 | 218.167 | 2.45357 | 7.75887 | 1.81914 | 3.91921 | 8.44369 | .166113 |
| 6.03 | 36.3609 | 219.256 | 2.45561 | 7.76531 | 1.82014 | 3.92138 | 8.44836 | .165838 |
| 6.04 | 36.4816 | 220.349 | 2.45764 | 7.77174 | 1.82115 | 3.92355 | 8.45303 | .165563 |
| 6.05 | 36.6025 | 221.445 | 2.45967 | 7.77817 | 1.82215 | 3.92571 | 8.45769 | .165289 |
| 6.06 | 36.7236 | 222.545 | 2.46171 | 7.78460 | 1.82316 | 3.92787 | 8.46235 | .165017 |
| 6.07 | 36.8449 | 223.649 | 2.46374 | 7.79102 | 1.82416 | 3.93003 | 8.46700 | .164745 |
| 6.08 | 36.9664 | 224.756 | 2.46577 | 7.79744 | 1.82516 | 3.93219 | 8.47165 | .164474 |
| 6.09 | 37.0881 | 225.867 | 2.46779 | 7.80385 | 1.82616 | 3.93434 | 8.47629 | .164204 |
| 6.10 | 37.2100 | 226.981 | 2.46982 | 7.81025 | 1.82716 | 3.93650 | 8.48093 | .163934 |
| 6.11 | 37.3321 | 228.099 | 2.47184 | 7.81665 | 1.82816 | 3.93865 | 8.48556 | .163666 |
| 6.12 | 37.4544 | 229.221 | 2.47386 | 7.82304 | 1.82915 | 3.94079 | 8.49018 | .163399 |
| 6.13 | 37.5769 | 230.346 | 2.47588 | 7.82943 | 1.83015 | 3.94294 | 8.49481 | .163132 |
| 6.14 | 37.6996 | 231.476 | 2.47790 | 7.83582 | 1.83115 | 3.94508 | 8.49942 | .162866 |
| 6.15 | 37.8225 | 232.608 | 2.47992 | 7.84219 | 1.83214 | 3.94722 | 8.50404 | .162602 |
| 6.16 | 37.9456 | 233.745 | 2.48193 | 7.84857 | 1.83313 | 3.94936 | 8.50864 | .162338 |
| 6.17 | 38.0689 | 234.885 | 2.48395 | 7.85493 | 1.83412 | 3.95150 | 8.51324 | .162075 |
| 6.18 | 38.1924 | 236.029 | 2.48596 | 7.86130 | 1.83511 | 3.95363 | 8.51784 | .161812 |
| 6.19 | 38.3161 | 237.177 | 2.48797 | 7.86766 | 1.83610 | 3.95576 | 8.52243 | .161551 |
| 6.20 | 38.4400 | 238.328 | 2.48998 | 7.87401 | 1.83709 | 3.95789 | 8.52702 | .161290 |
| 6.21 | 38.5641 | 239.483 | 2.49199 | 7.88036 | 1.83808 | 3.96002 | 8.53160 | .161031 |
| 6.22 | 38.6884 | 240.642 | 2.49399 | 7.88670 | 1.83906 | 3.96214 | 8.53618 | .160772 |
| 6.23 | 38.8129 | 241.804 | 2.49600 | 7.89303 | 1.84005 | 3.96426 | 8.54075 | .160514 |
| 6.24 | 38.9376 | 242.971 | 2.49800 | 7.89937 | 1.84103 | 3.96639 | 8.54532 | .160256 |
| 6.25 | 39.0625 | 244.141 | 2.50000 | 7.90569 | 1.84202 | 3.96850 | 8.54988 | .160000 |
| 6.26 | 39.1876 | 245.314 | 2.50200 | 7.91202 | 1.84300 | 3.97062 | 8.55444 | .159744 |
| 6.27 | 39.3129 | 246.492 | 2.50400 | 7.91833 | 1.84398 | 3.97273 | 8.55899 | .159490 |
| 6.28 | 39.4384 | 247.673 | 2.50599 | 7.92465 | 1.84496 | 3.97484 | 8.56354 | .159236 |
| 6.29 | 39.5641 | 248.858 | 2.50799 | 7.93095 | 1.84594 | 3.97695 | 8.56808 | .158983 |
| 6.30 | 39.6900 | 250.047 | 2.50998 | 7.93725 | 1.84691 | 3.97906 | 8.57262 | .158730 |
| 6.31 | 39.8161 | 251.240 | 2.51197 | 7.94355 | 1.84789 | 3.98116 | 8.57715 | .158479 |
| 6.32 | 39.9424 | 252.436 | 2.51396 | 7.94984 | 1.84887 | 3.98326 | 8.58168 | .158228 |
| 6.33 | 40.0689 | 253.636 | 2.51595 | 7.95613 | 1.84984 | 3.98536 | 8.58620 | .157978 |
| 6.34 | 40.1956 | 254.840 | 2.51794 | 7.96241 | 1.85082 | 3.98746 | 8.59072 | .157729 |
| 6.35 | 40.3225 | 256.048 | 2.51992 | 7.96869 | 1.85179 | 3.98956 | 8.59524 | .157480 |
| 6.36 | 40.4496 | 257.259 | 2.52190 | 7.97496 | 1.85276 | 3.99165 | 8.59975 | .157233 |
| 6.37 | 40.5769 | 258.475 | 2.52389 | 7.98123 | 1.85373 | 3.99374 | 8.60425 | .156986 |
| 6.38 | 40.7044 | 259.694 | 2.52587 | 7.98749 | 1.85470 | 3.99583 | 8.60875 | .156740 |
| 6.39 | 40.8321 | 260.917 | 2.52784 | 7.99375 | 1.85567 | 3.99792 | 8.61325 | .156495 |
| 6.40 | 40.9600 | 262.144 | 2.52982 | 8.00000 | 1.85664 | 4.00000 | 8.61774 | .156250 |
| 6.41 | 41.0881 | 263.375 | 2.53180 | 8.00625 | 1.85760 | 4.00208 | 8.62222 | .156006 |
| 6.42 | 41.2164 | 264.609 | 2.53377 | 8.01249 | 1.85857 | 4.00416 | 8.62671 | .155763 |
| 6.43 | 41.3449 | 265.848 | 2.53574 | 8.01873 | 1.85953 | 4.00624 | 8.63118 | .155521 |
| 6.44 | 41.4736 | 267.090 | 2.53772 | 8.02496 | 1.86050 | 4.00832 | 8.63566 | .155280 |
| 6.45 | 41.6025 | 268.336 | 2.53969 | 8.03119 | 1.86146 | 4.01039 | 8.64012 | .155039 |
| 6.46 | 41.7316 | 269.586 | 2.54165 | 8.03741 | 1.86242 | 4.01246 | 8.64459 | .154799 |
| 6.47 | 41.8609 | 270.840 | 2.54362 | 8.04363 | 1.86338 | 4.01453 | 8.64904 | .154560 |
| 6.48 | 41.9904 | 272.098 | 2.54558 | 8.04984 | 1.86434 | 4.01660 | 8.65350 | .154321 |
| 6.49 | 42.1201 | 273.359 | 2.54755 | 8.05605 | 1.86530 | 4.01866 | 8.65795 | .154083 |
| 6.50 | 42.2500 | 274.625 | 2.54951 | 8.06226 | 1.86626 | 4.02073 | 8.66239 | .153846 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10n}$ | $\sqrt[3]{100n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 6.51 | 42.3801 | 275.894 | 2.55147 | 8.06846 | 1.86721 | 4.02279 | 8.66683 | .153610 |
| 6.52 | 42.5104 | 277.168 | 2.55343 | 8.07465 | 1.86817 | 4.02485 | 8.67127 | .153374 |
| 6.53 | 42.6409 | 278.445 | 2.55539 | 8.08084 | 1.86912 | 4.02690 | 8.67570 | .153139 |
| 6.54 | 42.7716 | 279.726 | 2.55734 | 8.08703 | 1.87008 | 4.02896 | 8.68012 | .152905 |
| 6.55 | 42.9025 | 281.011 | 2.55930 | 8.09321 | 1.87103 | 4.03101 | 8.68455 | .152672 |
| 6.56 | 43.0336 | 282.300 | 2.56125 | 8.09938 | 1.87198 | 4.03306 | 8.68896 | .152439 |
| 6.57 | 43.1649 | 283.593 | 2.56320 | 8.10555 | 1.87293 | 4.03511 | 8.69338 | .152207 |
| 6.58 | 43.2964 | 284.890 | 2.56515 | 8.11172 | 1.87388 | 4.03715 | 8.69778 | .151976 |
| 6.59 | 43.4281 | 286.191 | 2.56710 | 8.11788 | 1.87483 | 4.03920 | 8.70219 | .151745 |
| 6.60 | 43.5600 | 287.496 | 2.56905 | 8.12404 | 1.87578 | 4.04124 | 8.70659 | .151515 |
| 6.61 | 43.6921 | 288.805 | 2.57099 | 8.13019 | 1.87672 | 4.04328 | 8.71098 | .151286 |
| 6.62 | 43.8244 | 290.118 | 2.57294 | 8.13634 | 1.87767 | 4.04532 | 8.71537 | .151057 |
| 6.63 | 43.9569 | 291.434 | 2.57488 | 8.14248 | 1.87862 | 4.04735 | 8.71976 | .150830 |
| 6.64 | 44.0896 | 292.755 | 2.57682 | 8.14862 | 1.87956 | 4.04939 | 8.72414 | .150602 |
| 6.65 | 44.2225 | 294.080 | 2.57876 | 8.15475 | 1.88050 | 4.05142 | 8.72852 | .150376 |
| 6.66 | 44.3556 | 295.408 | 2.58070 | 8.16088 | 1.88144 | 4.05345 | 8.73289 | .150150 |
| 6.67 | 44.4889 | 296.741 | 2.58263 | 8.16701 | 1.88239 | 4.05548 | 8.73726 | .149925 |
| 6.68 | 44.6224 | 298.078 | 2.58457 | 8.17313 | 1.88333 | 4.05750 | 8.74162 | .149701 |
| 6.69 | 44.7561 | 299.418 | 2.58650 | 8.17924 | 1.88427 | 4.05953 | 8.74598 | .149477 |
| 6.70 | 44.8900 | 300.763 | 2.58844 | 8.18535 | 1.88520 | 4.06155 | 8.75034 | .149254 |
| 6.71 | 45.0241 | 302.112 | 2.59037 | 8.19146 | 1.88614 | 4.06357 | 8.75469 | .149031 |
| 6.72 | 45.1584 | 303.464 | 2.59230 | 8.19756 | 1.88708 | 4.06558 | 8.75904 | .148810 |
| 6.73 | 45.2929 | 304.821 | 2.59422 | 8.20366 | 1.88801 | 4.06760 | 8.76338 | .148588 |
| 6.74 | 45.4276 | 306.182 | 2.59615 | 8.20975 | 1.88895 | 4.06961 | 8.76772 | .148368 |
| 6.75 | 45.5625 | 307.547 | 2.59808 | 8.21584 | 1.88988 | 4.07163 | 8.77205 | .148148 |
| 6.76 | 45.6976 | 308.916 | 2.60000 | 8.22192 | 1.89081 | 4.07364 | 8.77638 | .147929 |
| 6.77 | 45.8329 | 310.289 | 2.60192 | 8.22800 | 1.89175 | 4.07564 | 8.78071 | .147711 |
| 6.78 | 45.9684 | 311.666 | 2.60384 | 8.23408 | 1.89268 | 4.07765 | 8.78503 | .147493 |
| 6.79 | 46.1041 | 313.047 | 2.60576 | 8.24015 | 1.89361 | 4.07965 | 8.78935 | .147275 |
| 6.80 | 46.2400 | 314.432 | 2.60768 | 8.24621 | 1.89454 | 4.08166 | 8.79366 | .147059 |
| 6.81 | 46.3761 | 315.821 | 2.60960 | 8.25227 | 1.89546 | 4.08365 | 8.79797 | .146843 |
| 6.82 | 46.5124 | 317.215 | 2.61151 | 8.25833 | 1.89639 | 4.08565 | 8.80227 | .146628 |
| 6.83 | 46.6489 | 318.612 | 2.61343 | 8.26438 | 1.89732 | 4.08765 | 8.80657 | .146413 |
| 6.84 | 46.7856 | 320.014 | 2.61534 | 8.27043 | 1.89824 | 4.08964 | 8.81087 | .146199 |
| 6.85 | 46.9225 | 321.419 | 2.61725 | 8.27647 | 1.89917 | 4.09164 | 8.81516 | .145985 |
| 6.86 | 47.0596 | 322.829 | 2.61916 | 8.28251 | 1.90009 | 4.09362 | 8.81945 | .145773 |
| 6.87 | 47.1969 | 324.243 | 2.62107 | 8.28855 | 1.90102 | 4.09561 | 8.82373 | .145560 |
| 6.88 | 47.3344 | 325.661 | 2.62298 | 8.29458 | 1.90194 | 4.09760 | 8.82801 | .145349 |
| 6.89 | 47.4721 | 327.083 | 2.62488 | 8.30060 | 1.90286 | 4.09958 | 8.83229 | .145138 |
| 6.90 | 47.6100 | 328.509 | 2.62679 | 8.30662 | 1.90378 | 4.10157 | 8.83656 | .144928 |
| 6.91 | 47.7481 | 329.939 | 2.62869 | 8.31264 | 1.90470 | 4.10355 | 8.84082 | .144718 |
| 6.92 | 47.8864 | 331.374 | 2.63059 | 8.31865 | 1.90562 | 4.10552 | 8.84509 | .144509 |
| 6.93 | 48.0249 | 332.813 | 2.63249 | 8.32466 | 1.90653 | 4.10750 | 8.84934 | .144300 |
| 6.94 | 48.1636 | 334.255 | 2.63439 | 8.33067 | 1.90745 | 4.10948 | 8.85360 | .144092 |
| 6.95 | 48.3025 | 335.702 | 2.63629 | 8.33667 | 1.90837 | 4.11145 | 8.85785 | .143885 |
| 6.96 | 48.4416 | 337.154 | 2.63818 | 8.34266 | 1.90928 | 4.11342 | 8.86210 | .143678 |
| 6.97 | 48.5809 | 338.609 | 2.64008 | 8.34865 | 1.91019 | 4.11539 | 8.86634 | .143472 |
| 6.98 | 48.7204 | 340.068 | 2.64197 | 8.35464 | 1.91111 | 4.11736 | 8.87058 | .143267 |
| 6.99 | 48.8601 | 341.532 | 2.64386 | 8.36062 | 1.91202 | 4.11932 | 8.87481 | .143062 |
| 7.00 | 49.0000 | 343.000 | 2.64575 | 8.36660 | 1.91293 | 4.12129 | 8.87904 | .142857 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10\,n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10\,n}$ | $\sqrt[3]{100\,n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 7.01 | 49.1401 | 344.472 | 2.64764 | 8.37257 | 1.91384 | 4.12325 | 8.88327 | .142653 |
| 7.02 | 49.2804 | 345.948 | 2.64953 | 8.37854 | 1.91475 | 4.12521 | 8.88749 | .142450 |
| 7.03 | 49.4209 | 347.429 | 2.65141 | 8.38451 | 1.91566 | 4.12716 | 8.89171 | .142248 |
| 7.04 | 49.5616 | 348.914 | 2.65330 | 8.39047 | 1.91657 | 4.12912 | 8.89592 | .142046 |
| 7.05 | 49.7025 | 350.403 | 2.65518 | 8.39643 | 1.91747 | 4.13107 | 8.90013 | .141844 |
| 7.06 | 49.8436 | 351.896 | 2.65707 | 8.40238 | 1.91838 | 4.13303 | 8.90434 | .141643 |
| 7.07 | 49.9849 | 353.393 | 2.65895 | 8.40833 | 1.91929 | 4.13498 | 8.90854 | .141443 |
| 7.08 | 50.1264 | 354.895 | 2.66083 | 8.41427 | 1.92019 | 4.13695 | 8.91274 | .141243 |
| 7.09 | 50.2681 | 356.401 | 2.66271 | 8.42021 | 1.92109 | 4.13887 | 8.91693 | .141044 |
| 7.10 | 50.4100 | 357.911 | 2.66458 | 8.42615 | 1.92200 | 4.14082 | 8.92112 | .140845 |
| 7.11 | 50.5521 | 359.425 | 2.66646 | 8.43208 | 1.92290 | 4.14276 | 8.92531 | .140647 |
| 7.12 | 50.6944 | 360.944 | 2.66833 | 8.43801 | 1.92380 | 4.14470 | 8.92949 | .140449 |
| 7.13 | 50.8369 | 362.467 | 2.67021 | 8.44393 | 1.92470 | 4.14664 | 8.93367 | .140253 |
| 7.14 | 50.9796 | 363.994 | 2.67208 | 8.44985 | 1.92560 | 4.14858 | 8.93784 | .140056 |
| 7.15 | 51.1225 | 365.526 | 2.67395 | 8.45577 | 1.92650 | 4.15051 | 8.94201 | .139860 |
| 7.16 | 51.2656 | 367.062 | 2.67582 | 8.46168 | 1.92740 | 4.15245 | 8.94618 | .139665 |
| 7.17 | 51.4089 | 368.602 | 2.67769 | 8.46759 | 1.92829 | 4.15438 | 8.95034 | .139470 |
| 7.18 | 51.5524 | 370.146 | 2.67955 | 8.47349 | 1.92919 | 4.15631 | 8.95450 | .139276 |
| 7.19 | 51.6961 | 371.695 | 2.68142 | 8.47939 | 1.93008 | 4.15824 | 8.95866 | .139082 |
| 7.20 | 51.8400 | 373.248 | 2.68328 | 8.48528 | 1.93098 | 4.16017 | 8.96281 | .138889 |
| 7.21 | 51.9841 | 374.805 | 2.68514 | 8.49117 | 1.93187 | 4.16209 | 8.96696 | .138696 |
| 7.22 | 52.1284 | 376.367 | 2.68701 | 8.49706 | 1.93277 | 4.16402 | 8.97110 | .138504 |
| 7.23 | 52.2729 | 377.933 | 2.68887 | 8.50294 | 1.93366 | 4.16594 | 8.97524 | .138313 |
| 7.24 | 52.4176 | 379.503 | 2.69072 | 8.50882 | 1.93455 | 4.16786 | 8.97938 | .138122 |
| 7.25 | 52.5625 | 381.078 | 2.69258 | 8.51469 | 1.93544 | 4.16978 | 8.98351 | .137931 |
| 7.26 | 52.7076 | 382.657 | 2.69444 | 8.52056 | 1.93633 | 4.17169 | 8.98764 | .137741 |
| 7.27 | 52.8529 | 384.241 | 2.69629 | 8.52643 | 1.93722 | 4.17361 | 8.99176 | .137552 |
| 7.28 | 52.9984 | 385.828 | 2.69815 | 8.53229 | 1.93810 | 4.17552 | 8.99588 | .137363 |
| 7.29 | 53.1441 | 387.420 | 2.70000 | 8.53815 | 1.93899 | 4.17743 | 9.00000 | .137174 |
| 7.30 | 53.2900 | 389.017 | 2.70185 | 8.54400 | 1.93988 | 4.17934 | 9.00411 | .136986 |
| 7.31 | 53.4361 | 390.618 | 2.70370 | 8.54985 | 1.94076 | 4.18125 | 9.00822 | .136799 |
| 7.32 | 53.5824 | 392.223 | 2.70555 | 8.55570 | 1.94165 | 4.18315 | 9.01233 | .136612 |
| 7.33 | 53.7289 | 393.833 | 2.70740 | 8.56154 | 1.94253 | 4.18506 | 9.01643 | .136426 |
| 7.34 | 53.8756 | 395.447 | 2.70924 | 8.56738 | 1.94341 | 4.18696 | 9.02053 | .136240 |
| 7.35 | 54.0225 | 397.065 | 2.71109 | 8.57321 | 1.94430 | 4.18886 | 9.02462 | .136054 |
| 7.36 | 54.1696 | 398.688 | 2.71293 | 8.57904 | 1.94518 | 4.19076 | 9.02871 | .135870 |
| 7.37 | 54.3169 | 400.316 | 2.71477 | 8.58487 | 1.94606 | 4.19266 | 9.03280 | .135685 |
| 7.38 | 54.4644 | 401.947 | 2.71662 | 8.59069 | 1.94694 | 4.19455 | 9.03689 | .135501 |
| 7.39 | 54.6121 | 403.583 | 2.71846 | 8.59651 | 1.94782 | 4.19644 | 9.04097 | .135318 |
| 7.40 | 54.7600 | 405.224 | 2.72029 | 8.60233 | 1.94870 | 4.19834 | 9.04504 | .135135 |
| 7.41 | 54.9081 | 406.869 | 2.72213 | 8.60814 | 1.94957 | 4.20023 | 9.04911 | .134953 |
| 7.42 | 55.0564 | 408.518 | 2.72397 | 8.61394 | 1.95045 | 4.20212 | 9.05318 | .134771 |
| 7.43 | 55.2049 | 410.172 | 2.72580 | 8.61974 | 1.95132 | 4.20400 | 9.05725 | .134590 |
| 7.44 | 55.3536 | 411.831 | 2.72764 | 8.62554 | 1.95220 | 4.20589 | 9.06131 | .134409 |
| 7.45 | 55.5025 | 413.494 | 2.72947 | 8.63134 | 1.95307 | 4.20777 | 9.06537 | .134228 |
| 7.46 | 55.6516 | 415.161 | 2.73130 | 8.63713 | 1.95395 | 4.20965 | 9.06942 | .134048 |
| 7.47 | 55.8009 | 416.833 | 2.73313 | 8.64292 | 1.95482 | 4.21153 | 9.07347 | .133869 |
| 7.48 | 55.9504 | 418.509 | 2.73496 | 8.64870 | 1.95569 | 4.21341 | 9.07752 | .133690 |
| 7.49 | 56.1001 | 420.190 | 2.73679 | 8.65448 | 1.95656 | 4.21529 | 9.08156 | .133511 |
| 7.50 | 56.2500 | 421.875 | 2.73861 | 8.66025 | 1.95743 | 4.21716 | 9.08560 | .133333 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10n}$ | $\sqrt[3]{100n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 7.51 | 56.4001 | 423.565 | 2.74044 | 8.66603 | 1.95830 | 4.21904 | 9.08964 | .133156 |
| 7.52 | 56.5504 | 425.259 | 2.74226 | 8.67179 | 1.95917 | 4.22091 | 9.09367 | .132979 |
| 7.53 | 56.7009 | 426.958 | 2.74408 | 8.67756 | 1.96004 | 4.22278 | 9.09770 | .132802 |
| 7.54 | 56.8516 | 428.661 | 2.74591 | 8.68332 | 1.96091 | 4.22465 | 9.10173 | .132626 |
| 7.55 | 57.0025 | 430.369 | 2.74773 | 8.68907 | 1.96177 | 4.22651 | 9.10575 | .132450 |
| 7.56 | 57.1536 | 432.081 | 2.74955 | 8.69483 | 1.96264 | 4.22838 | 9.10977 | .132275 |
| 7.57 | 57.3049 | 433.798 | 2.75136 | 8.70057 | 1.96350 | 4.23024 | 9.11378 | .132100 |
| 7.58 | 57.4564 | 435.520 | 2.75318 | 8.70632 | 1.96437 | 4.23210 | 9.11779 | .131926 |
| 7.59 | 57.6081 | 437.245 | 2.75500 | 8.71206 | 1.96523 | 4.23396 | 9.12180 | .131752 |
| 7.60 | 57.7600 | 438.976 | 2.75681 | 8.71780 | 1.96610 | 4.23582 | 9.12581 | .131579 |
| 7.61 | 57.9121 | 440.711 | 2.75862 | 8.72353 | 1.96696 | 4.23768 | 9.12981 | .131406 |
| 7.62 | 58.0644 | 442.451 | 2.76043 | 8.72926 | 1.96782 | 4.23954 | 9.13380 | .131234 |
| 7.63 | 58.2169 | 444.195 | 2.76225 | 8.73499 | 1.96868 | 4.24139 | 9.13780 | .131062 |
| 7.64 | 58.3696 | 445.994 | 2.76405 | 8.74071 | 1.96954 | 4.24324 | 9.14179 | .130890 |
| 7.65 | 58.5225 | 447.697 | 2.76586 | 8.74643 | 1.97040 | 4.24509 | 9.14577 | .130719 |
| 7.66 | 58.6756 | 449.455 | 2.76767 | 8.75214 | 1.97126 | 4.24694 | 9.14976 | .130548 |
| 7.67 | 58.8289 | 451.218 | 2.76948 | 8.75785 | 1.97211 | 4.24879 | 9.15374 | .130378 |
| 7.68 | 58.9824 | 452.985 | 2.77128 | 8.76356 | 1.97297 | 4.25063 | 9.15771 | .130208 |
| 7.69 | 59.1361 | 454.757 | 2.77308 | 8.76926 | 1.97383 | 4.25248 | 9.16169 | .130039 |
| 7.70 | 59.2900 | 456.533 | 2.77489 | 8.77496 | 1.97468 | 4.25432 | 9.16566 | .129870 |
| 7.71 | 59.4441 | 458.314 | 2.77669 | 8.78066 | 1.97554 | 4.25616 | 9.16962 | .129702 |
| 7.72 | 59.5984 | 460.100 | 2.77849 | 8.78635 | 1.97639 | 4.25800 | 9.17359 | .129534 |
| 7.73 | 59.7529 | 461.890 | 2.78029 | 8.79204 | 1.97724 | 4.25984 | 9.17754 | .129366 |
| 7.74 | 59.9076 | 463.685 | 2.78209 | 8.79773 | 1.97809 | 4.26168 | 9.18150 | .129199 |
| 7.75 | 60.0625 | 465.484 | 2.78388 | 8.80341 | 1.97895 | 4.26351 | 9.18545 | .129032 |
| 7.76 | 60.2176 | 467.289 | 2.78568 | 8.80909 | 1.97980 | 4.26534 | 9.18940 | .128866 |
| 7.77 | 60.3729 | 469.097 | 2.78747 | 8.81476 | 1.98065 | 4.26717 | 9.19335 | .128700 |
| 7.78 | 60.5284 | 470.911 | 2.78927 | 8.82043 | 1.98150 | 4.26900 | 9.19729 | .128535 |
| 7.79 | 60.6841 | 472.729 | 2.79106 | 8.82610 | 1.98234 | 4.27083 | 9.20123 | .128370 |
| 7.80 | 60.8400 | 474.552 | 2.79285 | 8.83176 | 1.98319 | 4.27266 | 9.20516 | .128205 |
| 7.81 | 60.9961 | 476.380 | 2.79464 | 8.83742 | 1.98404 | 4.27448 | 9.20910 | .128041 |
| 7.82 | 61.1524 | 478.212 | 2.79643 | 8.84308 | 1.98489 | 4.27631 | 9.21303 | .127877 |
| 7.83 | 61.3089 | 480.049 | 2.79821 | 8.84873 | 1.98573 | 4.27813 | 9.21695 | .127714 |
| 7.84 | 61.4656 | 481.890 | 2.80000 | 8.85438 | 1.98658 | 4.27995 | 9.22087 | .127551 |
| 7.85 | 61.6225 | 483.737 | 2.80179 | 8.86002 | 1.98742 | 4.28177 | 9.22479 | .127389 |
| 7.86 | 61.7796 | 485.588 | 2.80357 | 8.86566 | 1.98826 | 4.28359 | 9.22871 | .127227 |
| 7.87 | 61.9369 | 487.443 | 2.80535 | 8.87130 | 1.98911 | 4.28540 | 9.23262 | .127065 |
| 7.88 | 62.0944 | 489.304 | 2.80713 | 8.87694 | 1.98995 | 4.28722 | 9.23653 | .126904 |
| 7.89 | 62.2521 | 491.169 | 2.80891 | 8.88257 | 1.99079 | 4.28903 | 9.24043 | .126743 |
| 7.90 | 62.4100 | 493.039 | 2.81069 | 8.88819 | 1.99163 | 4.29084 | 9.24433 | .126582 |
| 7.91 | 62.5681 | 494.914 | 2.81247 | 8.89382 | 1.99247 | 4.29265 | 9.24823 | .126422 |
| 7.92 | 62.7264 | 496.793 | 2.81425 | 8.89944 | 1.99331 | 4.29446 | 9.25213 | .126263 |
| 7.93 | 62.8849 | 498.677 | 2.81603 | 8.90505 | 1.99415 | 4.29627 | 9.25602 | .126103 |
| 7.94 | 63.0436 | 500.566 | 2.81780 | 8.91067 | 1.99499 | 4.29807 | 9.25991 | .125945 |
| 7.95 | 63.2025 | 502.460 | 2.81957 | 8.91628 | 1.99582 | 4.29987 | 9.26380 | .125786 |
| 7.96 | 63.3616 | 504.358 | 2.82135 | 8.92188 | 1.99666 | 4.30168 | 9.26768 | .125628 |
| 7.97 | 63.5209 | 506.262 | 2.82312 | 8.92749 | 1.99750 | 4.30348 | 9.27156 | .125471 |
| 7.98 | 63.6804 | 508.170 | 2.82489 | 8.93308 | 1.99833 | 4.30528 | 9.27544 | .125313 |
| 7.99 | 63.8401 | 510.082 | 2.82666 | 8.93868 | 1.99917 | 4.30707 | 9.27931 | .125156 |
| 8.00 | 64.0000 | 512.000 | 2.82843 | 8.94427 | 2.00000 | 4.30887 | 9.28318 | .125000 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10\,n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10\,n}$ | $\sqrt[3]{100\,n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 8.01 | 64.1601 | 513.922 | 2.83019 | 8.94986 | 2.00083 | 4.31066 | 9.28704 | .124844 |
| 8.02 | 64.3204 | 515.850 | 2.83196 | 8.95545 | 2.00167 | 4.31246 | 9.29091 | .124688 |
| 8.03 | 64.4809 | 517.782 | 2.83373 | 8.96103 | 2.00250 | 4.31425 | 9.29477 | .124533 |
| 8.04 | 64.6416 | 519.718 | 2.83549 | 8.96660 | 2.00333 | 4.31604 | 9.29862 | .124378 |
| 8.05 | 64.8025 | 521.660 | 2.83725 | 8.97218 | 2.00416 | 4.31783 | 9.30248 | .124224 |
| 8.06 | 64.9636 | 523.607 | 2.83901 | 8.97775 | 2.00499 | 4.31961 | 9.30633 | .124070 |
| 8.07 | 65.1249 | 525.558 | 2.84077 | 8.98332 | 2.00582 | 4.32140 | 9.31018 | .123916 |
| 8.08 | 65.2864 | 527.514 | 2.84253 | 8.98888 | 2.00664 | 4.32318 | 9.31402 | .123762 |
| 8.09 | 65.4481 | 529.475 | 2.84429 | 8.99444 | 2.00747 | 4.32497 | 9.31786 | .123609 |
| 8.10 | 65.6100 | 531.441 | 2.84605 | 9.00000 | 2.00830 | 4.32675 | 9.32170 | .123457 |
| 8.11 | 65.7721 | 533.412 | 2.84781 | 9.00555 | 2.00912 | 4.32853 | 9.32553 | .123305 |
| 8.12 | 65.9344 | 535.387 | 2.84956 | 9.01110 | 2.00995 | 4.33031 | 9.32936 | .123153 |
| 8.13 | 66.0969 | 537.368 | 2.85132 | 9.01665 | 2.01078 | 4.33208 | 9.33319 | .123001 |
| 8.14 | 66.2596 | 539.353 | 2.85307 | 9.02219 | 2.01160 | 4.33386 | 9.33702 | .122850 |
| 8.15 | 66.4225 | 541.343 | 2.85482 | 9.02774 | 2.01242 | 4.33563 | 9.34084 | .122699 |
| 8.16 | 66.5856 | 543.338 | 2.85657 | 9.03327 | 2.01325 | 4.33741 | 9.34466 | .122549 |
| 8.17 | 66.7489 | 545.339 | 2.85832 | 9.03881 | 2.01407 | 4.33918 | 9.34847 | .122399 |
| 8.18 | 66.9124 | 547.343 | 2.86007 | 9.04434 | 2.01489 | 4.34095 | 9.35229 | .122249 |
| 8.19 | 67.0761 | 549.353 | 2.86182 | 9.04986 | 2.01571 | 4.34272 | 9.35610 | .122100 |
| 8.20 | 67.2400 | 551.368 | 2.86356 | 9.05539 | 2.01653 | 4.34448 | 9.35990 | .121951 |
| 8.21 | 67.4041 | 553.388 | 2.86531 | 9.06091 | 2.01735 | 4.34625 | 9.36370 | .121803 |
| 8.22 | 67.5684 | 555.412 | 2.86705 | 9.06642 | 2.01817 | 4.34801 | 9.36751 | .121655 |
| 8.23 | 67.7329 | 557.442 | 2.86880 | 9.07193 | 2.01899 | 4.34977 | 9.37130 | .121507 |
| 8.24 | 67.8976 | 559.476 | 2.87054 | 9.07744 | 2.01980 | 4.35153 | 9.37510 | .121359 |
| 8.25 | 68.0625 | 561.516 | 2.87228 | 9.08295 | 2.02062 | 4.35329 | 9.37889 | .121212 |
| 8.26 | 68.2276 | 563.560 | 2.87402 | 9.08845 | 2.02144 | 4.35505 | 9.38268 | .121065 |
| 8.27 | 68.3929 | 565.609 | 2.87576 | 9.09395 | 2.02225 | 4.35681 | 9.38646 | .120919 |
| 8.28 | 68.5584 | 567.664 | 2.87750 | 9.09945 | 2.02307 | 4.35856 | 9.39024 | .120773 |
| 8.29 | 68.7241 | 569.723 | 2.87924 | 9.10494 | 2.02388 | 4.36032 | 9.39402 | .120627 |
| 8.30 | 68.8900 | 571.787 | 2.88097 | 9.11043 | 2.02469 | 4.36207 | 9.39780 | .120482 |
| 8.31 | 69.0561 | 573.856 | 2.88271 | 9.11592 | 2.02551 | 4.36382 | 9.40157 | .120337 |
| 8.32 | 69.2224 | 575.930 | 2.88444 | 9.12140 | 2.02632 | 4.36557 | 9.40534 | .120192 |
| 8.33 | 69.3889 | 578.010 | 2.88617 | 9.12688 | 2.02713 | 4.36732 | 9.40911 | .120048 |
| 8.34 | 69.5556 | 580.094 | 2.88791 | 9.13236 | 2.02794 | 4.36907 | 9.41287 | .119904 |
| 8.35 | 69.7225 | 582.183 | 2.88964 | 9.13783 | 2.02875 | 4.37081 | 9.41663 | .119761 |
| 8.36 | 69.8896 | 584.277 | 2.89137 | 9.14330 | 2.02956 | 4.37255 | 9.42039 | .119617 |
| 8.37 | 70.0569 | 586.376 | 2.89310 | 9.14877 | 2.03037 | 4.37430 | 9.42414 | .119474 |
| 8.38 | 70.2244 | 588.480 | 2.89482 | 9.15423 | 2.03118 | 4.37604 | 9.42789 | .119332 |
| 8.39 | 70.3921 | 590.590 | 2.89655 | 9.15969 | 2.03199 | 4.37778 | 9.43164 | .119190 |
| 8.40 | 70.5600 | 592.704 | 2.89828 | 9.16515 | 2.03279 | 4.37952 | 9.43539 | .119048 |
| 8.41 | 70.7281 | 594.823 | 2.90000 | 9.17061 | 2.03360 | 4.38126 | 9.43913 | .118906 |
| 8.42 | 70.8964 | 596.948 | 2.90172 | 9.17606 | 2.03440 | 4.38299 | 9.44287 | .118765 |
| 8.43 | 71.0649 | 599.077 | 2.90345 | 9.18150 | 2.03521 | 4.38473 | 9.44661 | .118624 |
| 8.44 | 71.2336 | 601.212 | 2.90517 | 9.18695 | 2.03601 | 4.38646 | 9.45034 | .118483 |
| 8.45 | 71.4025 | 603.351 | 2.90689 | 9.19239 | 2.03682 | 4.38819 | 9.45407 | .118343 |
| 8.46 | 71.5716 | 605.496 | 2.90861 | 9.19783 | 2.03762 | 4.38992 | 9.45780 | .118203 |
| 8.47 | 71.7409 | 607.645 | 2.91033 | 9.20326 | 2.03842 | 4.39165 | 9.46152 | .118064 |
| 8.48 | 71.9104 | 609.800 | 2.91204 | 9.20869 | 2.03923 | 4.39338 | 9.46525 | .117925 |
| 8.49 | 72.0801 | 611.960 | 2.91376 | 9.21412 | 2.04003 | 4.39511 | 9.46897 | .117786 |
| 8.50 | 72.2500 | 614.125 | 2.91548 | 9.21954 | 2.04083 | 4.39683 | 9.47268 | .117647 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10\,n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10\,n}$ | $\sqrt[3]{100\,n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| **8.51** | 72.4201 | 616.295 | 2.91719 | 9.22497 | 2.04163 | 4.39855 | 9.47640 | .117509 |
| **8.52** | 72.5904 | 618.470 | 2.91890 | 9.23038 | 2.04243 | 4.40028 | 9.48011 | .117371 |
| **8.53** | 72.7609 | 620.650 | 2.92062 | 9.23580 | 2.04323 | 4.40200 | 9.48381 | .117233 |
| **8.54** | 72.9316 | 622.836 | 2.92233 | 9.24121 | 2.04402 | 4.40372 | 9.48752 | .117096 |
| **8.55** | 73.1025 | 625.026 | 2.92404 | 9.24662 | 2.04482 | 4.40543 | 9.49122 | .116959 |
| **8.56** | 73.2736 | 627.222 | 2.92575 | 9.25203 | 2.04562 | 4.40715 | 9.49492 | .116822 |
| **8.57** | 73.4449 | 629.423 | 2.92746 | 9.25743 | 2.04641 | 4.40887 | 9.49861 | .116686 |
| **8.58** | 73.6164 | 631.629 | 2.92916 | 9.26283 | 2.04721 | 4.41058 | 9.50231 | .116550 |
| **8.59** | 73.7881 | 633.840 | 2.93087 | 9.26823 | 2.04801 | 4.41229 | 9.50600 | .116414 |
| **8.60** | 73.9600 | 636.056 | 2.93258 | 9.27362 | 2.04880 | 4.41400 | 9.50969 | .116279 |
| **8.61** | 74.1321 | 638.277 | 2.93428 | 9.27901 | 2.04959 | 4.41571 | 9.51337 | .116144 |
| **8.62** | 74.3044 | 640.504 | 2.93598 | 9.28440 | 2.05039 | 4.41742 | 9.51705 | .116009 |
| **8.63** | 74.4769 | 642.736 | 2.93769 | 9.28978 | 2.05118 | 4.41913 | 9.52073 | .115875 |
| **8.64** | 74.6496 | 644.973 | 2.93939 | 9.29516 | 2.05197 | 4.42084 | 9.52441 | .115741 |
| **8.65** | 74.8225 | 647.215 | 2.94109 | 9.30054 | 2.05276 | 4.42254 | 9.52808 | .115607 |
| **8.66** | 74.9956 | 649.462 | 2.94279 | 9.30591 | 2.05355 | 4.42425 | 9.53175 | .115473 |
| **8.67** | 75.1689 | 651.714 | 2.94449 | 9.31128 | 2.05434 | 4.42595 | 9.53542 | .115340 |
| **8.68** | 75.3424 | 653.972 | 2.94618 | 9.31665 | 2.05513 | 4.42765 | 9.53908 | .115207 |
| **8.69** | 75.5161 | 656.235 | 2.94788 | 9.32202 | 2.05592 | 4.42935 | 9.54274 | .115075 |
| **8.70** | 75.6900 | 658.503 | 2.94958 | 9.32738 | 2.05671 | 4.43105 | 9.54640 | .114943 |
| **8.71** | 75.8641 | 660.776 | 2.95127 | 9.33274 | 2.05750 | 4.43274 | 9.55006 | .114811 |
| **8.72** | 76.0384 | 663.055 | 2.95296 | 9.33809 | 2.05828 | 4.43444 | 9.55371 | .114679 |
| **8.73** | 76.2129 | 665.339 | 2.95466 | 9.34345 | 2.05907 | 4.43614 | 9.55736 | .114548 |
| **8.74** | 76.3876 | 667.628 | 2.95635 | 9.34880 | 2.05986 | 4.43783 | 9.56101 | .114417 |
| **8.75** | 76.5625 | 669.922 | 2.95804 | 9.35414 | 2.06064 | 4.43952 | 9.56466 | .114286 |
| **8.76** | 76.7376 | 672.221 | 2.95973 | 9.35949 | 2.06143 | 4.44121 | 9.56830 | .114155 |
| **8.77** | 76.9129 | 674.526 | 2.96142 | 9.36483 | 2.06221 | 4.44290 | 9.57194 | .114025 |
| **8.78** | 77.0884 | 676.836 | 2.96311 | 9.37017 | 2.06299 | 4.44459 | 9.57557 | .113895 |
| **8.79** | 77.2641 | 679.151 | 2.96479 | 9.37550 | 2.06378 | 4.44627 | 9.57921 | .113766 |
| **8.80** | 77.4400 | 681.472 | 2.96648 | 9.38083 | 2.06456 | 4.44796 | 9.58284 | .113636 |
| **8.81** | 77.6161 | 683.798 | 2.96816 | 9.38616 | 2.06534 | 4.44964 | 9.58647 | .113507 |
| **8.82** | 77.7924 | 686.129 | 2.96985 | 9.39149 | 2.06612 | 4.45133 | 9.59009 | .113379 |
| **8.83** | 77.9689 | 688.465 | 2.97153 | 9.39681 | 2.06690 | 4.45301 | 9.59372 | .113250 |
| **8.84** | 78.1456 | 690.807 | 2.97321 | 9.40213 | 2.06768 | 4.45469 | 9.59734 | .113122 |
| **8.85** | 78.3225 | 693.154 | 2.97489 | 9.40744 | 2.06846 | 4.45637 | 9.60095 | .112994 |
| **8.86** | 78.4996 | 695.506 | 2.97658 | 9.41276 | 2.06924 | 4.45805 | 9.60457 | .112867 |
| **8.87** | 78.6769 | 697.864 | 2.97825 | 9.41807 | 2.07002 | 4.45972 | 9.60818 | .112740 |
| **8.88** | 78.8544 | 700.227 | 2.97993 | 9.42338 | 2.07080 | 4.46140 | 9.61179 | .112613 |
| **8.89** | 79.0321 | 702.595 | 2.98161 | 9.42868 | 2.07157 | 4.46307 | 9.61540 | .112486 |
| **8.90** | 79.2100 | 704.969 | 2.98329 | 9.43398 | 2.07235 | 4.46474 | 9.61900 | .112360 |
| **8.91** | 79.3881 | 707.348 | 2.98496 | 9.43928 | 2.07313 | 4.46642 | 9.62260 | .112233 |
| **8.92** | 79.5664 | 709.732 | 2.98664 | 9.44458 | 2.07390 | 4.46809 | 9 62620 | .112108 |
| **8.93** | 79.7449 | 712.122 | 2.98831 | 9.44987 | 2.07468 | 4.46976 | 9.62980 | .111982 |
| **8.94** | 79.9236 | 714.517 | 2.98998 | 9.45516 | 2.07545 | 4.47142 | 9.63339 | .111857 |
| **8.95** | 80.1025 | 716.917 | 2.99166 | 9.46044 | 2.07622 | 4.47309 | 9.63698 | .111732 |
| **8.96** | 80.2816 | 719.323 | 2.99333 | 9.46573 | 2.07700 | 4.47476 | 9.64057 | .111607 |
| **8.97** | 80.4609 | 721.734 | 2.99500 | 9.47101 | 2.07777 | 4.47642 | 9.64415 | .111483 |
| **8.98** | 80.6404 | 724.151 | 2.99666 | 9.47629 | 2.07854 | 4.47808 | 9.64774 | .111359 |
| **8.99** | 80.8201 | 726.573 | 2.99833 | 9.48156 | 2.07931 | 4.47974 | 9.65132 | .111235 |
| **9.00** | 81.0000 | 729.000 | 3.00000 | 9.48683 | 2.08008 | 4.48140 | 9.65489 | .111111 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10n}$ | $\sqrt[3]{100n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 9.01 | 81.1801 | 731.433 | 3.00167 | 9.49210 | 2.08085 | 4.48306 | 9.65847 | .110988 |
| 9.02 | 81.3604 | 733.871 | 3.00333 | 9.49737 | 2.08162 | 4.48472 | 9.66204 | .110865 |
| 9.03 | 81.5409 | 736.314 | 3.00500 | 9.50263 | 2.08239 | 4.48638 | 9.66561 | .110742 |
| 9.04 | 81.7216 | 738.763 | 3.00666 | 9.50789 | 2.08316 | 4.48803 | 9.66918 | .110620 |
| 9.05 | 81.9025 | 741.218 | 3.00832 | 9.51315 | 2.08393 | 4.48968 | 9.67274 | .110497 |
| 9.06 | 82.0836 | 743.677 | 3.00998 | 9.51840 | 2.08470 | 4.49134 | 9.67630 | .110375 |
| 9.07 | 82.2649 | 746.143 | 3.01164 | 9.52365 | 2.08546 | 4.49299 | 9.67986 | .110254 |
| 9.08 | 82.4464 | 748.613 | 3.01330 | 9.52890 | 2.08623 | 4.49464 | 9.68342 | .110132 |
| 9.09 | 82.6281 | 751.089 | 3.01496 | 9.53415 | 2.08699 | 4.49629 | 9.68697 | .110011 |
| 9.10 | 82.8100 | 753.571 | 3.01662 | 9.53939 | 2.08776 | 4.49794 | 9.69052 | .109890 |
| 9.11 | 82.9921 | 756.058 | 3.01828 | 9.54463 | 2.08852 | 4.49959 | 9.69407 | .109770 |
| 9.12 | 83.1744 | 758.551 | 3.01993 | 9.54987 | 2.08929 | 4.50123 | 9.69762 | .109649 |
| 9.13 | 83.3569 | 761.048 | 3.02159 | 9.55510 | 2.09005 | 4.50288 | 9.70116 | .109529 |
| 9.14 | 83.5396 | 763.552 | 3.02324 | 9.56033 | 2.09081 | 4.50452 | 9.70470 | .109409 |
| 9.15 | 83.7225 | 766.061 | 3.02490 | 9.56556 | 2.09158 | 4.50616 | 9.70824 | .109290 |
| 9.16 | 83.9056 | 768.575 | 3.02655 | 9.57079 | 2.09234 | 4.50780 | 9.71177 | .109170 |
| 9.17 | 84.0889 | 771.095 | 3.02820 | 9.57601 | 2.09310 | 4.50945 | 9.71531 | .109051 |
| 9.18 | 84.2724 | 773.621 | 3.02985 | 9.58123 | 2.09386 | 4.51108 | 9.71884 | .108933 |
| 9.19 | 84.4561 | 776.152 | 3.03150 | 9.58645 | 2.09462 | 4.51272 | 9.72236 | .108814 |
| 9.20 | 84.6400 | 778.688 | 3.03315 | 9.59166 | 2.09538 | 4.51436 | 9.72589 | .108696 |
| 9.21 | 84.8241 | 781.230 | 3.03480 | 9.59687 | 2.09614 | 4.51599 | 9.72941 | .108578 |
| 9.22 | 85.0084 | 783.777 | 3.03645 | 9.60208 | 2.09690 | 4.51763 | 9.73293 | .108460 |
| 9.23 | 85.1929 | 786.330 | 3.03809 | 9.60729 | 2.09765 | 4.51926 | 9.73645 | .108342 |
| 9.24 | 85.3776 | 788.889 | 3.03974 | 9.61249 | 2.09841 | 4.52089 | 9.73996 | .108225 |
| 9.25 | 85.5625 | 791.453 | 3.04138 | 9.61769 | 2.09917 | 4.52252 | 9.74348 | .108108 |
| 9.26 | 85.7476 | 794.023 | 3.04302 | 9.62289 | 2.09992 | 4.52415 | 9.74699 | .107991 |
| 9.27 | 85.9329 | 796.598 | 3.04467 | 9.62808 | 2.10068 | 4.52578 | 9.75049 | .107875 |
| 9.28 | 86.1184 | 799.179 | 3.04631 | 9.63328 | 2.10144 | 4.52740 | 9.75400 | .107759 |
| 9.29 | 86.3041 | 801.765 | 3.04795 | 9.63846 | 2.10219 | 4.52903 | 9.75750 | .107643 |
| 9.30 | 86.4900 | 804.357 | 3.04959 | 9.64365 | 2.10294 | 4.53065 | 9.76100 | .107527 |
| 9.31 | 86.6761 | 806.954 | 3.05123 | 9.64883 | 2.10370 | 4.53228 | 9.76450 | .107411 |
| 9.32 | 86.8624 | 809.558 | 3.05287 | 9.65401 | 2.10445 | 4.53390 | 9.76799 | .107296 |
| 9.33 | 87.0489 | 812.166 | 3.05450 | 9.65919 | 2.10520 | 4.53552 | 9.77148 | .107181 |
| 9.34 | 87.2356 | 814.781 | 3.05614 | 9.66437 | 2.10595 | 4.53714 | 9.77497 | .107066 |
| 9.35 | 87.4225 | 817.400 | 3.05778 | 9.66954 | 2.10671 | 4.53876 | 9.77846 | .106952 |
| 9.36 | 87.6096 | 820.026 | 3.05941 | 9.67471 | 2.10746 | 4.54038 | 9.78195 | .106838 |
| 9.37 | 87.7969 | 822.657 | 3.06105 | 9.67988 | 2.10821 | 4.54199 | 9.78543 | .106724 |
| 9.38 | 87.9844 | 825.294 | 3.06268 | 9.68504 | 2.10896 | 4.54361 | 9.78891 | .106610 |
| 9.39 | 88.1721 | 827.936 | 3.06431 | 9.69020 | 2.10971 | 4.54522 | 9.79239 | .106496 |
| 9.40 | 88.3600 | 830.584 | 3.06594 | 9.69536 | 2.11045 | 4.54684 | 9.79586 | .106383 |
| 9.41 | 88.5481 | 833.238 | 3.06757 | 9.70052 | 2.11120 | 4.54845 | 9.79933 | .106270 |
| 9.42 | 88.7364 | 835.897 | 3.06920 | 9.70567 | 2.11195 | 4.55006 | 9.80280 | .106157 |
| 9.43 | 88.9249 | 838.562 | 3.07083 | 9.71082 | 2.11270 | 4.55167 | 9.80627 | .106045 |
| 9.44 | 89.1136 | 841.232 | 3.07246 | 9.71597 | 2.11344 | 4.55328 | 9.80974 | .105932 |
| 9.45 | 89.3025 | 843.909 | 3.07409 | 9.72111 | 2.11419 | 4.55488 | 9.81320 | .105820 |
| 9.46 | 89.4916 | 846.591 | 3.07571 | 9.72625 | 2.11494 | 4.55649 | 9.81666 | .105708 |
| 9.47 | 89.6809 | 849.278 | 3.07734 | 9.73139 | 2.11568 | 4.55809 | 9.82012 | .105597 |
| 9.48 | 89.8704 | 851.971 | 3.07896 | 9.73653 | 2.11642 | 4.55970 | 9.82357 | .105485 |
| 9.49 | 90.0601 | 854.670 | 3.08058 | 9.74166 | 2.11717 | 4.56130 | 9.82703 | .105374 |
| 9.50 | 90.2500 | 857.375 | 3.08221 | 9.74679 | 2.11791 | 4.56290 | 9.83048 | .105263 |

| $n$ | $n^2$ | $n^3$ | $\sqrt{n}$ | $\sqrt{10n}$ | $\sqrt[3]{n}$ | $\sqrt[3]{10n}$ | $\sqrt[3]{100n}$ | $\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|---|
| 9.51 | 90.4401 | 860.085 | 3.08383 | 9.75192 | 2.11865 | 4.56450 | 9.83392 | .105153 |
| 9.52 | 90.6304 | 862.801 | 3.08545 | 9.75705 | 2.11940 | 4.56610 | 9.83737 | .105042 |
| 9.53 | 90.8209 | 865.523 | 3.08707 | 9.76217 | 2.12014 | 4.56770 | 9.84081 | .104932 |
| 9.54 | 91.0116 | 868.251 | 3.08869 | 9.76729 | 2.12088 | 4.56930 | 9.84425 | .104822 |
| 9.55 | 91.2025 | 870.984 | 3.09031 | 9.77241 | 2.12162 | 4.57089 | 9.84769 | .104712 |
| 9.56 | 91.3936 | 873.723 | 3.09192 | 9.77753 | 2.12236 | 4.57249 | 9.85113 | .104603 |
| 9.57 | 91.5849 | 876.467 | 3.09354 | 9.78264 | 2.12310 | 4.57408 | 9.85456 | .104493 |
| 9.58 | 91.7764 | 879.218 | 3.09516 | 9.78775 | 2.12384 | 4.57568 | 9.85799 | .104384 |
| 9.59 | 91.9681 | 881.974 | 3.09677 | 9.79285 | 2.12458 | 4.57727 | 9.86142 | .104275 |
| 9.60 | 92.1600 | 884.736 | 3.09839 | 9.79796 | 2.12532 | 4.57886 | 9.86485 | .104167 |
| 9.61 | 92.3521 | 887.504 | 3.10000 | 9.80306 | 2.12605 | 4.58045 | 9.86827 | .104058 |
| 9.62 | 92.5444 | 890.277 | 3.10161 | 9.80816 | 2.12679 | 4.58203 | 9.87169 | .103950 |
| 9.63 | 92.7369 | 893.056 | 3.10322 | 9.81326 | 2.12753 | 4.58362 | 9.87511 | .103842 |
| 9.64 | 92.9296 | 895.841 | 3.10483 | 9.81835 | 2.12826 | 4.58521 | 9.87853 | .103734 |
| 9.65 | 93.1225 | 898.632 | 3.10644 | 9.82344 | 2.12900 | 4.58679 | 9.88195 | .103627 |
| 9.66 | 93.3156 | 901.429 | 3.10805 | 9.82853 | 2.12974 | 4.58838 | 9.88536 | .103520 |
| 9.67 | 93.5089 | 904.231 | 3.10966 | 9.83362 | 2.13047 | 4.58996 | 9.88877 | .103413 |
| 9.68 | 93.7024 | 907.039 | 3.11127 | 9.83870 | 2.13120 | 4.59154 | 9.89217 | .103306 |
| 9.69 | 93.8961 | 909.853 | 3.11288 | 9.84378 | 2.13194 | 4.59312 | 9.89558 | .103199 |
| 9.70 | 94.0900 | 912.673 | 3.11448 | 9.84886 | 2.13267 | 4.59470 | 9.89898 | .103093 |
| 9.71 | 94.2841 | 915.499 | 3.11609 | 9.85393 | 2.13340 | 4.59628 | 9.90238 | .102987 |
| 9.72 | 94.4784 | 918.330 | 3.11769 | 9.85901 | 2.13414 | 4.59786 | 9.90578 | .102881 |
| 9.73 | 94.6729 | 921.167 | 3.11929 | 9.86408 | 2.13487 | 4.59943 | 9.90918 | .102775 |
| 9.74 | 94.8676 | 924.010 | 3.12090 | 9.86914 | 2.13560 | 4.60101 | 9.91257 | .102669 |
| 9.75 | 95.0625 | 926.859 | 3.12250 | 9.87421 | 2.13633 | 4.60258 | 9.91596 | .102564 |
| 9.76 | 95.2576 | 929.714 | 3.12410 | 9.87927 | 2.13706 | 4.60416 | 9.91935 | .102459 |
| 9.77 | 95.4529 | 932.575 | 3.12570 | 9.88433 | 2.13779 | 4.60573 | 9.92274 | .102354 |
| 9.78 | 95.6484 | 935.441 | 3.12730 | 9.88939 | 2.13852 | 4.60730 | 9.92612 | .102250 |
| 9.79 | 95.8441 | 938.314 | 3.12890 | 9.89444 | 2.13925 | 4.60887 | 9.92950 | .102145 |
| 9.80 | 96.0400 | 941.192 | 3.13050 | 9.89949 | 2.13997 | 4.61044 | 9.93288 | .102041 |
| 9.81 | 96.2361 | 944.076 | 3.13209 | 9.90454 | 2.14070 | 4.61200 | 9.93626 | .101937 |
| 9.82 | 96.4324 | 946.966 | 3.13369 | 9.90959 | 2.14143 | 4.61357 | 9.93964 | .101833 |
| 9.83 | 96.6289 | 949.862 | 3.13528 | 9.91464 | 2.14216 | 4.61513 | 9.94301 | .101729 |
| 9.84 | 96.8256 | 952.764 | 3.13688 | 9.91968 | 2.14288 | 4.61670 | 9.94638 | .101626 |
| 9.85 | 97.0225 | 955.672 | 3.13847 | 9.92472 | 2.14361 | 4.61826 | 9.94975 | .101523 |
| 9.86 | 97.2196 | 958.585 | 3.14006 | 9.92975 | 2.14433 | 4.61983 | 9.95311 | .101420 |
| 9.87 | 97.4169 | 961.505 | 3.14166 | 9.93479 | 2.14506 | 4.62139 | 9.95648 | .101317 |
| 9.88 | 97.6144 | 964.430 | 3.14325 | 9.93982 | 2.14578 | 4.62295 | 9.95984 | .101215 |
| 9.89 | 97.8121 | 967.362 | 3.14484 | 9.94485 | 2.14651 | 4.62451 | 9.96320 | .101112 |
| 9.90 | 98.0100 | 970.299 | 3.14643 | 9.94987 | 2.14723 | 4.62607 | 9.96655 | .101010 |
| 9.91 | 98.2081 | 973.242 | 3.14802 | 9.95490 | 2.14795 | 4.62762 | 9.96991 | .100908 |
| 9.92 | 98.4064 | 976.191 | 3.14960 | 9.95992 | 2.14867 | 4.62918 | 9.97326 | .100807 |
| 9.93 | 98.6049 | 979.147 | 3.15119 | 9.96494 | 2.14940 | 4.63073 | 9.97661 | .100705 |
| 9.94 | 98.8036 | 982.108 | 3.15278 | 9.96995 | 2.15012 | 4.63229 | 9.97996 | .100604 |
| 9.95 | 99.0025 | 985.075 | 3.15436 | 9.97497 | 2.15084 | 4.63384 | 9.98331 | .100503 |
| 9.96 | 99.2016 | 988.048 | 3.15595 | 9.97998 | 2.15156 | 4.63539 | 9.98665 | .100402 |
| 9.97 | 99.4009 | 991.027 | 3.15753 | 9.98499 | 2.15228 | 4.63694 | 9.98999 | .100301 |
| 9.98 | 99.6004 | 994.012 | 3.15911 | 9.98999 | 2.15300 | 4.63849 | 9.99333 | .100200 |
| 9.99 | 99.8001 | 997.003 | 3.16070 | 9.99500 | 2.15372 | 4.64004 | 9.99667 | .100100 |
| 10.00 | 100.000 | 1000.00 | 3.16228 | 10.0000 | 2.15443 | 4.64159 | 10.0000 | .100000 |

## DECIMAL EQUIVALENTS OF 64ths.

The decimal fractions printed in Roman give the value of the corresponding fraction to the fourth decimal place. A given decimal fraction is rarely exactly equal to one of these values, and the numbers in *Italic* show which common fraction is nearest to the given decimal. Thus, lay off the fraction .1330 in 64ths. The nearest decimal fractions are .1250 and .1406. The value of any fraction in Italic is the mean of the two adjacent fractions. In this instance, the mean fraction is .1328, and as .1330 is greater than this, .1406 or $\frac{9}{64}$ will be chosen. In the same manner the nearest 64ths corresponding to the decimal fractions .3670 and .8979 are found to be $\frac{23}{64}$ and $\frac{57}{64}$, respectively.

| Fraction | Decimal | Fraction | Decimal | Fraction | Decimal | Fraction | Decimal |
|---|---|---|---|---|---|---|---|
| | *.0078* | | *.2578* | | *.5078* | | *.7578* |
| $\frac{1}{64}$ | .0156 | $\frac{17}{64}$ | .2656 | $\frac{33}{64}$ | .5156 | $\frac{49}{64}$ | .7656 |
| | *.0235* | | *.2735* | | *.5235* | | *.7735* |
| $\frac{1}{32}$ | .0313 | $\frac{9}{32}$ | .2813 | $\frac{17}{32}$ | .5313 | $\frac{25}{32}$ | .7813 |
| | *.0391* | | *.2891* | | *.5391* | | *.7891* |
| $\frac{3}{64}$ | .0469 | $\frac{19}{64}$ | .2969 | $\frac{35}{64}$ | .5469 | $\frac{51}{64}$ | .7969 |
| | *.0547* | | *.3047* | | *.5547* | | *.8047* |
| $\frac{1}{16}$ | .0625 | $\frac{5}{16}$ | .3125 | $\frac{9}{16}$ | .5625 | $\frac{13}{16}$ | .8125 |
| | *.0703* | | *.3203* | | *.5703* | | *.8203* |
| $\frac{5}{64}$ | .0781 | $\frac{21}{64}$ | .3281 | $\frac{37}{64}$ | .5781 | $\frac{53}{64}$ | .8281 |
| | *.0860* | | *.3360* | | *.5860* | | *.8360* |
| $\frac{3}{32}$ | .0938 | $\frac{11}{32}$ | .3438 | $\frac{19}{32}$ | .5938 | $\frac{27}{32}$ | .8438 |
| | *.1016* | | *.3516* | | *.6016* | | *.8516* |
| $\frac{7}{64}$ | .1094 | $\frac{23}{64}$ | .3594 | $\frac{39}{64}$ | .6094 | $\frac{55}{64}$ | .8594 |
| | *.1172* | | *.3672* | | *.6172* | | *.8672* |
| $\frac{1}{8}$ | .1250 | $\frac{3}{8}$ | .3750 | $\frac{5}{8}$ | .6250 | $\frac{7}{8}$ | .8750 |
| | *.1328* | | *.3828* | | *.6328* | | *.8828* |
| $\frac{9}{64}$ | .1406 | $\frac{25}{64}$ | .3906 | $\frac{41}{64}$ | .6406 | $\frac{57}{64}$ | .8906 |
| | *.1485* | | *.3985* | | *.6485* | | *.8985* |
| $\frac{5}{32}$ | .1563 | $\frac{13}{32}$ | .4063 | $\frac{21}{32}$ | .6563 | $\frac{29}{32}$ | .9063 |
| | *.1641* | | *.4141* | | *.6641* | | *.9141* |
| $\frac{11}{64}$ | .1719 | $\frac{27}{64}$ | .4219 | $\frac{43}{64}$ | .6719 | $\frac{59}{64}$ | .9219 |
| | *.1797* | | *.4297* | | *.6797* | | *.9297* |
| $\frac{3}{16}$ | .1875 | $\frac{7}{16}$ | .4375 | $\frac{11}{16}$ | .6875 | $\frac{15}{16}$ | .9375 |
| | *.1953* | | *.4453* | | *.6953* | | *.9453* |
| $\frac{13}{64}$ | .2031 | $\frac{29}{64}$ | .4531 | $\frac{45}{64}$ | .7031 | $\frac{61}{64}$ | .9531 |
| | *.2110* | | *.4610* | | *.7110* | | *.9610* |
| $\frac{7}{32}$ | .2188 | $\frac{15}{32}$ | .4688 | $\frac{23}{32}$ | .7188 | $\frac{31}{32}$ | .9688 |
| | *.2266* | | *.4766* | | *.7266* | | *.9766* |
| $\frac{15}{64}$ | .2344 | $\frac{31}{64}$ | .4844 | $\frac{47}{64}$ | .7344 | $\frac{63}{64}$ | .9844 |
| | *.2422* | | *.4922* | | *.7422* | | *.9922* |
| $\frac{1}{4}$ | .2500 | $\frac{1}{2}$ | .5000 | $\frac{3}{4}$ | .7500 | 1 | 1.0000 |
| | *.2578* | | *.5078* | | *.7578* | | *1.0078* |

| In. | 0″ | 1″ | 2″ | 3″ | 4″ | 5″ | 6″ | 7″ | 8″ | 9″ | 10″ | 11″ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | .0833 | .1667 | .2500 | .3333 | .4167 | .5000 | .5833 | .6667 | .7500 | .8333 | .9167 |
| $\frac{1}{32}$ | .0026 | .0859 | .1693 | .2526 | .3359 | .4193 | .5026 | .5859 | .6693 | .7526 | .8359 | .9193 |
| $\frac{1}{16}$ | .0052 | .0885 | .1719 | .2552 | .3385 | .4219 | .5052 | .5885 | .6719 | .7552 | .8385 | .9219 |
| $\frac{3}{32}$ | .0078 | .0911 | .1745 | .2578 | .3411 | .4245 | .5078 | .5911 | .6745 | .7578 | .8411 | 9245 |
| $\frac{1}{8}$ | .0104 | .0937 | .1771 | .2604 | .3437 | .4271 | .5104 | .5937 | .6771 | .7604 | .8437 | .9271 |
| $\frac{5}{32}$ | .0130 | .0964 | .1797 | .2630 | .3464 | .4297 | .5130 | .5964 | .6797 | .7630 | .8464 | .9297 |
| $\frac{3}{16}$ | .0156 | .0990 | .1823 | .2656 | .3490 | .4323 | .5156 | .5990 | .6823 | .7656 | .8490 | .9323 |
| $\frac{7}{32}$ | .0182 | .1016 | .1849 | .2682 | .3516 | .4349 | .5182 | .6016 | .6849 | .7682 | .8516 | .9349 |
| $\frac{1}{4}$ | .0208 | .1042 | .1875 | .2708 | .3542 | .4375 | .5208 | .6042 | .6875 | .7708 | .8542 | .9375 |
| $\frac{9}{32}$ | .0234 | .1068 | .1901 | .2734 | .3568 | .4401 | .5234 | .6068 | .6901 | .7734 | .8568 | .9401 |
| $\frac{5}{16}$ | .0260 | .1094 | .1927 | .2760 | .3594 | .4427 | .5260 | .6094 | .6927 | .7760 | .8594 | .9427 |
| $\frac{11}{32}$ | .0286 | .1120 | .1953 | .2786 | .3620 | .4453 | .5286 | .6120 | .6953 | .7786 | .8620 | .9453 |
| $\frac{3}{8}$ | .0312 | .1146 | .1979 | .2812 | .3646 | .4479 | .5312 | .6146 | .6979 | .7812 | .8646 | .9479 |
| $\frac{13}{32}$ | .0339 | .1172 | .2005 | 2839 | .3672 | .4505 | .5339 | .6172 | .7005 | .7839 | .8672 | .9505 |
| $\frac{7}{16}$ | .0365 | .1198 | .2031 | .2865 | .3698 | .4531 | .5365 | .6198 | .7031 | .7865 | .8698 | .9531 |
| $\frac{15}{32}$ | .0391 | .1224 | .2057 | .2891 | 3724 | .4557 | .5391 | .6224 | .7057 | .7891 | .8724 | .9557 |
| $\frac{1}{2}$ | .0417 | .1250 | .2083 | 2917 | .3750 | .4583 | .5417 | .6250 | .7083 | .7917 | .8750 | .9583 |
| $\frac{17}{32}$ | .0443 | .1276 | .2109 | .2943 | .3776 | .4609 | .5443 | .6276 | .7109 | .7943 | .8776 | .9609 |
| $\frac{9}{16}$ | .0469 | .1302 | .2135 | .2969 | .3802 | .4635 | .5469 | .6302 | .7135 | .7969 | .8802 | .9635 |
| $\frac{19}{32}$ | .0495 | .1328 | .2161 | .2995 | .3828 | .4661 | .5495 | .6328 | .7161 | .7995 | .8828 | .9661 |
| $\frac{5}{8}$ | .0521 | .1354 | .2188 | .3021 | .3854 | .4688 | .5521 | .6354 | .7188 | .8021 | .8854 | .9688 |
| $\frac{21}{32}$ | .0547 | .1380 | .2214 | .3047 | .3880 | .4714 | .5547 | .6380 | .7214 | .8047 | .8880 | .9714 |
| $\frac{11}{16}$ | .0573 | .1406 | .2240 | .3073 | .3906 | .4740 | .5573 | .6406 | .7240 | .8073 | .8906 | .9740 |
| $\frac{23}{32}$ | .0599 | .1432 | .2266 | .3099 | 3932 | .4766 | .5599 | .6432 | .7266 | 8099 | .8932 | .9766 |
| $\frac{3}{4}$ | .0625 | .1458 | .2292 | .3125 | .3958 | .4792 | .5625 | .6458 | .7292 | .8125 | .8958 | .9792 |
| $\frac{25}{32}$ | .0651 | .1484 | .2318 | .3151 | .3984 | .4818 | .5651 | .6484 | .7318 | .8151 | .8984 | .9818 |
| $\frac{13}{16}$ | .0677 | .1510 | .2344 | .3177 | .4010 | .4844 | .5677 | .6510 | .7344 | .8177 | .9010 | .9844 |
| $\frac{27}{32}$ | .0703 | .1536 | .2370 | .3203 | .4036 | .4870 | .5703 | .6536 | .7370 | .8203 | .9036 | .9870 |
| $\frac{7}{8}$ | .0729 | .1562 | .2396 | .3229 | .4062 | .4896 | .5729 | .6562 | .7396 | .8229 | .9062 | .9896 |
| $\frac{29}{32}$ | .0755 | .1589 | .2422 | .3255 | .4089 | .4922 | .5755 | .6589 | .7422 | .8255 | .9089 | .9922 |
| $\frac{15}{16}$ | .0781 | .1615 | .2448 | .3281 | .4115 | .4948 | .5781 | .6615 | .7448 | .8281 | .9115 | .9948 |
| $\frac{31}{32}$ | .0807 | .1641 | .2474 | .3307 | .4141 | .4974 | .5807 | .6641 | .7474 | .8307 | .9141 | .9974 |

# WEIGHTS AND MEASURES

## LINEAR MEASURE

| | | |
|---|---|---|
| 12 inches (in.) | = 1 foot | ft. |
| 3 feet | = 1 yard | yd. |
| $5\frac{1}{2}$ yards | = 1 rod | rd. |
| 40 rods | = 1 furlong | fur. |
| 8 furlongs | = 1 mile | mi. |

| *in.* | *ft.* | *yd.* | *rd.* | *fur.* | *mi.* |
|---|---|---|---|---|---|
| 36 = | 3 = | 1 | | | |
| 198 = | $16\frac{1}{2}$ = | $5\frac{1}{2}$ = | 1 | | |
| 7,920 = | 660 = | 220 = | 40 = | 1 | |
| 63,360 = | 5,280 = | 1,760 = | 320 = | 8 = | 1 |

## SURVEYOR'S MEASURE

| | | |
|---|---|---|
| 7.92 inches | = 1 link | li. |
| 25 links | = 1 rod | rd |
| 4 rods = 100 links = 66 feet | = 1 chain | ch. |
| 80 chains | = 1 mile | mi. |

| *mi.* | *ch.* | *rd.* | *li.* | *in.* |
|---|---|---|---|---|
| 1 = | 80 = | 320 = | 8,000 = | 63,360 |

## SQUARE MEASURE

| | | |
|---|---|---|
| 144 square inches (sq. in.) | = 1 square foot | sq. ft. |
| 9 square feet | = 1 square yard | sq. yd. |
| $30\frac{1}{4}$ square yards | = 1 square rod | sq. rd. |
| 160 square rods | = 1 acre | A. |
| 640 acres | = 1 square mile | sq. mi. |

| *sq. mi.* | *A.* | *sq. rd.* | *sq. yd.* | *sq. ft.* | *sq. in.* |
|---|---|---|---|---|---|
| 1 = | 640 = | 102,400 = | 3,097,600 = | 27,878,400 = | 4,014,489,600 |

## SURVEYOR'S SQUARE MEASURE

| | | |
|---|---|---|
| 625 square links (sq. li.) | = 1 square rod | sq. rd. |
| 16 square rods | = 1 square chain | sq. ch. |
| 10 square chains | = 1 acre | A. |
| 640 acres | = 1 square mile | sq. mi. |
| 36 square miles (6 mi. square) | = 1 township | Tp. |

| *sq. mi.* | *A.* | *sq. ch.* | *sq. rd.* | *sq. li.* |
|---|---|---|---|---|
| 1 = | 640 = | 6,400 = | 102,400 = | 64,000,000 |

The acre contains 4,840 sq. yd., or 43,560 sq. ft., and in form of a square is 208.71 ft. on a side.

## CUBIC MEASURE

| | | |
|---|---|---|
| 1,728 cubic inches (cu. in.) | = 1 cubic foot | cu. ft. |
| 27 cubic feet | = 1 cubic yard | cu. yd. |
| 128 cubic feet | = 1 cord | cd. |
| $24\frac{3}{4}$ cubic feet | = 1 perch | P. |

*cu. yd.* *cu. ft.* *cu. in.*
1 = 27 = 46,656

## MEASURE OF ANGLES OR ARCS

| | | |
|---|---|---|
| 60 seconds ($''$) | = 1 minute | $'$ |
| 60 minutes | = 1 degree | $^\circ$ |
| 90 degrees | = 1 rt. angle or quadrant | □ |
| 360 degrees | = 1 circle | cir. |

1 cir. $= 360^\circ = 21{,}600' = 1{,}296{,}000''$

## AVOIRDUPOIS WEIGHT

| | | |
|---|---|---|
| $437\frac{1}{2}$ grains (gr.) | = 1 ounce | oz. |
| 16 ounces | = 1 pound | lb. |
| 100 pounds | = 1 hundredweight | cwt. |
| 20 hundredweight or 2,000 lb | = 1 ton | T. |

*T.* *cwt.* *lb.* *oz.* *gr.*
1 = 20 = 2,000 = 32,000 = 14,000,000

The avoirdupois pound contains 7,000 grains.

## LONG TON TABLE

| | | |
|---|---|---|
| 16 ounces | = 1 pound | lb. |
| 112 pounds | = 1 hundredweight | cwt. |
| 20 hundredweight, or 2,240 lb. | = 1 ton | T. |

## TROY WEIGHT

| | | |
|---|---|---|
| 24 grains (gr.) | = 1 pennyweight | pwt. |
| 20 pennyweights | = 1 ounce | oz. |
| 12 ounces | = 1 pound | lb. |

*lb.* *oz.* *pwt.* *gr.*
1 = 12 = 240 = 5,760

## DRY MEASURE

| | | |
|---|---|---|
| 2 pints (pt.) | = 1 quart | qt. |
| 8 quarts | = 1 peck | pk. |
| 4 pecks | = 1 bushel | bu. |

*bu.* *pk.* *qt.* *pt.*
1 = 4 = 32 = 64

The *U. S. struck bushel* contains 2,150.42 cu. in. = 1.2444 cu. ft. Its dimensions are, by law, $18\frac{1}{2}$ in. in diameter and 8 in. deep.

The *heaped bushel* is equal to $1\frac{1}{4}$ struck bushels, the cone being 6 in. high.

For approximations, the bushel may be taken at $1\frac{1}{4}$ cu. ft.; or 1 cu. ft. may be considered $\frac{4}{5}$ bu.

The *British bushel* contains 2,218.19 cu. in. = 1.2837 cu. ft. = 1.032 U. S. bushels.

The *dry gallon* contains 268.8 cu. in., being $\frac{1}{8}$ bu.

## LIQUID MEASURE

| | | |
|---|---|---|
| 4 gills (gi.) | = 1 pint | pt. |
| 2 pints | = 1 quart | qt. |
| 4 quarts | = 1 gallon | gal. |
| $31\frac{1}{2}$ gallons | = 1 barrel | bbl. |
| 2 barrels, or 63 gallons | = 1 hogshead | hhd. |

| *hhd.* | *bbl.* | *gal.* | *qt.* | *pt.* | *gi.* |
|---|---|---|---|---|---|
| 1 = | 2 = | 63 = | 252 = | 504 = | 2,016 |

The *U. S. gallon* contains 231 cu. in. = .134 cu. ft., nearly; or 1 cu. ft. contains 7.48 gal.

The following cylinders contain the given measures very closely:

| | *Diam. Inches* | *Height Inches* | | *Diam. Inches* | *Height Inches* |
|---|---|---|---|---|---|
| Gill | $1\frac{3}{4}$ | 3 | Gallon | 7 | 6 |
| Pint | $3\frac{1}{2}$ | 3 | 8 gallons | 14 | 12 |
| Quart | $3\frac{1}{2}$ | 6 | 10 gallons | 14 | 15 |

With water at its maximum density 1 cu. ft. weighs 62.425 lb. and 1 gal. of pure water weighs 8.345 lb.

For approximations, 1 cu. ft. of water is considered equal to $7\frac{1}{2}$ gal., and 1 gal. as weighing $8\frac{1}{3}$ lb.

The *British imperial gallon*, both liquid and dry, contains 277.274 cu. in = .16046 cu. ft., and is equivalent to the volume of 10 lb. of pure water at 62° F.

To reduce U. S. to British liquid gallons, divide by 1.2. Conversely, to convert British into U. S. liquid gallons, multiply by 1.2; or, increase the number of gallons $\frac{1}{5}$.

### MISCELLANEOUS TABLE

| | | | |
|---|---|---|---|
| 12 articles | = 1 dozen. | 20 quires | = 1 ream. |
| 12 dozen | = 1 gross. | 1 league | = 3 mi. |
| 12 gross | = 1 great gross. | 1 fathom | = 6 ft. |
| 2 articles | = 1 pair. | 1 hand | = 4 in. |
| 20 articles | = 1 score. | 1 palm | = 3 in. |
| 24 sheets | = 1 quire. | 1 span | = 9 in. |

1 knot (U. S.) = 6,080 ft. = 1.15 mi. (roughly).

1 meter = 3 ft. $3\frac{3}{8}$ in. (nearly).

---

## THE METRIC SYSTEM

The *metric system* is based on the meter, which, according to the U. S. Coast and Geodetic Survey Report of 1884, is equal to 39.370432 in. The value commonly used is 39.37 in., and is authorized by the U. S. government. The meter is defined as one ten-millionth the distance from the pole to the equator, measured on a meridian passing near Paris.

There are three principal units—the meter, the liter (pronounced lee-ter), and the gram, the units of length, capacity, and weight, respectively. Multiples of these units are obtained by prefixing to the names of the principal units the Greek words *deca* (10), *hecto* (100), and *kilo* (1,000); the submultiples, or divisions, are obtained by prefixing the Latin words *deci* ($\frac{1}{10}$), *centi* ($\frac{1}{100}$), and *milli* ($\frac{1}{1000}$). These prefixes form the key to the entire system. In the following tables, the abbreviations of the principal units of these submultiples begin with a small letter, while those of the multiples begin with a capital letter; they should always be written as here printed.

### MEASURES OF LENGTH

| *Name* | | *Meters* | | *U.S. In.* | | *U.S. Ft.* |
|---|---|---|---|---|---|---|
| Millimeter (mm.) | = | .001 | = | .039370 | = | .003281 |
| Centimeter (cm.) | = | .010 | = | .393704 | = | .032809 |
| Decimeter (dm.) | = | .100 | = | 3.937043 | = | .328087 |
| Meter (m.) | = | 1.000 | = | 39.370432 | = | 3.280869 |
| Decameter (Dm.) | = | 10.000 | | | = | 32.808690 |
| Hectometer (Hm.) | = | 100.000 | | | = | 328.086900 |
| Kilometer (Km.) | = | 1,000.000 | = | .621 mi. | = | 3,280.869000 |
| Myriameter (Mm.) | = | 10,000.000 | = | 6.214 mi. | = | 32,808.690000 |

The centimeter, meter, and kilometer are the units in practical use, and may be said to occupy the same position in the metric system as do inches, yards, and miles in the U. S. and English system of measurement.

## MEASURES OF AREA

| *Name* | *Sq. M.* | *Sq. In.* | *Sq. Ft.* | *A.* |
|---|---|---|---|---|
| Sq. millimeter (sq. mm.) | = .0000010 = | .001550 | | |
| Sq. centimeter (sq. cm.) | = .0001000 = | .155003 = | .00107641 | |
| Sq. decimeter (sq. dm.) | = .0100000 = | 15.5003 = | .10764100 | |
| Sq. meter, or centare (sq.m., or ca.) | = 1.000000 = | 1,550.03 = | 10.764100 = | .000247 |
| Sq.decameter, or are (sq. Dm., or A.) | = 100.0000 = | 155,003 = | 1,076.4101 = | .024710 |
| Hectare | = 10,000.00 | | = 107,641.01 = | 2.47110 |
| Sq. kilometer | = .3861099 sq. mi. | | = 10,764,101 = | 247.110 |
| Sq. myriameter | = 38.61090 sq. mi. | | | = 24,711.0 |

## MEASURES OF VOLUME

| *Name* | *Cu. M.* | *Cu. In.* | *Cu. Ft.* | *Cu.Yd.* |
|---|---|---|---|---|
| Cu. centimeter (c.c. or cu.cm.) | = .000001 = | .061025 | | |
| Cu. decimeter (cu. dm.) | = .001000 = | 61.0254 | | |
| Centistere | = .010000 = | 610.2540 | = .35316 | |
| Decistere | = .100000 | | = 3.53156 | |
| Stere (cu. m.) | = 1.000000 | | = 35.3156 | = 1.308 |
| Decastere | = 10.000000 | | = 353.156 | = 13.080 |

## MEASURES OF CAPACITY

| *Name* | *Liters* | *Liq. Meas.* | *Dry Meas.* |
|---|---|---|---|
| Milliliter (ml. = c.c.) | = .00100 = | .008454 gi. | = .001816 pt. |
| Centiliter (cl.) | = .01000 = | .084537 gi. | = .018162 pt. |
| Deciliter (dl.) | = .10000 = | .845370 gi. | = .18162 pt. |
| Liter (l.) (= cu.dm.) | = 1.0000 = | 1.05671 qt.<br>.264179 gal. | = .11351 pk. |

| | | |
|---|---|---|
| Decaliter (Dl.) (= centistere) | = 10.000 = | 2.64179 gal. = 1.1351 pk. |
| Hectoliter (Hl.) (= decistere) | = 100.00 = | 26.4179 gal. = 2.83783 bu. |
| Kiloliter (Kl.) (= cu.m., or stere) | = 1,000.0 = | 264.179 gal. = 28.3783 bu. |
| Myrialiter (Ml.) (= decastere) | = 10,000 = | 2641.79 gal. = 283.783 bu. |

The milliliter (or cubic centimeter) and the liter are the units most commonly used. A liter of pure water at 4° C., or 39.2° F., weighs 1 Kg.

## METRIC WEIGHTS

The gram is the basis of metric weights, and is the weight of a cubic centimeter of distilled water at its maximum density, at sea level, Paris, barometer 29.922 inches.

| *Name* | *Grams* | *Grains* | *Av. Oz.* | *Av. Lb.* |
|---|---|---|---|---|
| Milligram (mg.) | .001 | .01543 | | |
| Centigram (cg.) | .010 | .15432 | | |
| Decigram (dg.) | .100 | 1.54323 | | |
| Gram (g.) | 1.000 | 15.43235 | .03527 | .0022046 |
| Decagram (Dg.) | 10.000 | | .35274 | .0220462 |
| Hectogr'm (Hg) | 100.000 | | 3.52739 | .2204622 |
| Kilogram (Kg.) | 1,000.000 | | 35.27395 | 2.2046223 |
| Myriagr'm (Mg) | 10,000.000 | | | 22.0462234 |
| Quintal (Q.) | 100,000.000 | | | 220.4622341 |
| Tonneau (T.) | 1,000,000.000 | | | 2,204.6223410 |

The gram and the kilogram (called *kilo*) are the units in common use.

## FACTORS FOR CONVERSION

For approximations, it may be useful to remember the following:

1 cm. = .4 in. (nearly)
1 m. = 40 in. (roughly)
1 Km. = $\frac{5}{8}$ mi. (nearly)
1 l. = 1 liq. qt. (nearly)
1 l. = $\frac{1}{9}$ pk. (nearly)
1 gr. = 15.4 gr.
1 Kg. = $2\frac{1}{5}$ lb.

To convert metric measures into U. S. measures, by use of the preceding tables, find the desired equivalent in U. S. measure of a metric unit of the denomination given, and multiply this equivalent by the metric number. For example, it is desired to find the equivalent in pounds of 19.6 Kg.

From the table of weights 1 Kg. = 2.2046 lb.; hence, 19.6 Kg. = 2.2046 × 19.6 = 43.21 lb. In similar manner, 8 l. = .264179 × 8 = 2.113432 U. S. gal.

To convert U. S. measures into metric measures, find how much a metric unit of the desired denomination is equal to in U. S. measure, and divide the given number by this equivalent. For example, it is desired to convert 4½ mi. into kilometers. From the table of lengths, it is found that 1 Km. is .621 mi.; hence, dividing 4.5 by .621, the result is 7.24 Km.

Other useful conversion factors are as follows:

**Length.**—1 in. = .0254 m.; 1 ft. = .3048 m.; 1 yd. = .9144 m.; 1 mi. = 1,609.34 m. = 1.609 Km.

**Area.**—1 sq. in. = .000645 sq. m.; 1 sq. ft. = .0929 sq. m.; 1 sq. yd. = .836 sq. m.; 1 A. = 4,047 sq. m.

**Capacity.**—1 cu. in. = .0164 l.; 1 U. S. bu. = 35.24 l.; 1 U. S. dry qt. = 1.101 l.; 1 U. S. pk. = 8.81 l.; 1 cu. yd. = 765 l.; 1 U. S. liq. qt. = .9463 l.; 1 U. S. gal. = 3.785 l.

**Weight.**—1 grain = .0648 gram; 1 av. oz. = 28.349 grams; 1 Troy oz. = 31.103 grams; 1 av. lb. = 453.59 grams.

## FORMULAS

*Formulas* are simply short methods of indicating operations otherwise expressed by rules, by using letters and signs in place of words. The letters are usually those of the English alphabet, and the signs are those previously given. Besides showing at a glance the various steps, formulas are much more convenient to memorize than rules and also can be more readily followed. Explanations will be given of some simple formulas, and it will be shown how a formula may be transposed so as to obtain any required term.

To show the similarity between a rule and a formula, let it be required to find the area of footing necessary to sustain a certain load, having given the safe load per square foot.

The rule is: *Divide the total load, in pounds, by the safe load, in pounds per square foot; the quotient is the required area, in square feet.* Not much space can be saved by expressing such a simple rule in a formula, but the operation is more quickly comprehended. Let $P$ = total load, in pounds; $S$ = safe load per square foot; $A$ = required area.

Then the rule is expressed by the formula

$$A = \frac{P}{S}$$

A formula is used by substituting for the letters the quantities known in the problem, and finding the unknown quantity by performing the indicated operations. Sometimes the formula as written does not give the desired quantity directly, but must be rearranged so as to enable it to be found. This is done by simple operations, the aim being to obtain the desired quantity by itself on one side of the equality sign. Thus, in the foregoing formula, suppose it is desired to find the value of $P$ when $A$ and $S$ are given. By multiplying $A$ and $\frac{P}{S}$ by $S$ (such operation being called *clearing of fractions*) there results $A \times S = P$, in which the desired quantity $P$ is by itself and is found to be equal to the product of $A$ and $S$. The formula is further shortened by omitting the $\times$ sign, and writing $A\,S = P$. When two or more letters are thus written, it means that they are to be multiplied together. In a similar manner, $S$ may be obtained by dividing the last found formula through by $A$; thus, $S = \frac{P}{A}$.

EXAMPLE 1.—The safe bearing power of a soil is 1,500 lb. per sq. ft. What area of footing is required to sustain a load of 30,000 lb.?

SOLUTION.—Here $A$ is wanted, and $P$ and $S$ are given. Hence, $A = \frac{P}{S} = \frac{30{,}000}{1{,}500} = 20$ sq. ft.

EXAMPLE 2.—If the total load is 30,000 lb., how much, per square foot, will be carried by a footing 20 sq. ft. in area?

SOLUTION.—Here, $A$ and $P$ are given to find $S$; or $S=\frac{P}{A}=\frac{30{,}000}{20}=1{,}500$ lb.

The following formula is used to determine the safe total quiescent load that a wooden beam will carry, if uniformly loaded:

$$W=c\frac{bd^2}{l}$$

in which, $b$ = breadth of beam, in inches;
$d$ = depth of beam, in inches;
$c$ = a constant, depending on kind of wood, etc.;
$l$ = length of span, in inches;
$W$ = safe total load, uniformly distributed.

If any other quantity than $W$ is wanted it may be found by transposing the formula; thus, if the depth necessary to sustain a certain load is required, the formula is changed by multiplying through by $l$.

$Wl=bd^2c$. Dividing by $bc$, $d^2=\frac{Wl}{bc}$. Extracting the square root, $d=\sqrt{\frac{Wl}{bc}}$

EXAMPLE.—It is desired to carry a distributed load of 10,000 lb. on a dry long-leaf pine beam 8 in. wde and 8 ft. 4 in. span. How thick must the beam be?

SOLUTION.—The value to be given to $c$ may be calculated from the transverse strength of the beam. It depends on the kind of wood, quality of wood, dryness of wood, method in which beam is placed, kind of load, and degree of safety required. In this problem it will be taken as 1,600. Substituting the values there results,

$$d=\sqrt{\frac{10{,}000\times 100}{8\times 1{,}600}}=\sqrt{78.125}=8.8 \text{ in. say } 9 \text{ in.}$$

A rule for finding the strength of a wooden column is as follows:

**Rule.**—*From the ultimate compressive strength of the material, in pounds per square inch, subtract the fraction; the ultimate strength multiplied by the length of column, in inches, and divided by 100 times the least side, in inches. The difference is the ultimate strength of the column in pounds per square inch.*

This rule is rendered much more intelligible by the formula, in which

$S$ = ultimate strength of column, in pounds per square inch;
$U$ = ultimate compressive strength of material in pounds per square inch;
$l$ = length of column, in inches;
$d$ = least side of column, in inches.

$$S = U - \frac{Ul}{100\,d};$$

The values of $U$ for different woods are found in tables. (See page 78.)

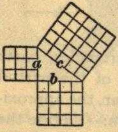
EXAMPLE.—The ultimate compressive stress of white pine, parallel to the grain, is 3,500 lb. per sq. in. What is the ultimate load per square inch that a 10″×10″ column 20 ft. long will carry?

SOLUTION.—After investigating the problem, it is found that all the quantities in the formula are given except $S$; the length expressed in inches = 240 in.; and the least side is 10 in., as the column is square. Substituting these values in the formula

$$S = 3{,}500 - \frac{3{,}500 \times 240}{100 \times 10} = 3{,}500 - 840 = 2{,}660 \text{ lb.}$$

## MENSURATION

### TRIANGLE




For a right triangle

Hypotenuse $c = \sqrt{a^2 + b^2}$

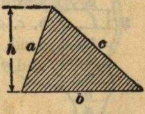
Side $a = \sqrt{c^2 - b^2}$

Side $b = \sqrt{c^2 - a^2}$

Area $= \frac{1}{2}\,ab$

For an oblique triangle. If altitude or height $h$ and base $b$ are known:

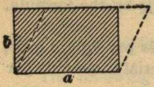
Area $= \frac{1}{2}\,bh$




If the three sides are known:

let $s = \frac{1}{2}(a + b + c)$

Area $= \sqrt{s(s-a)(s-b)(s-c)}$

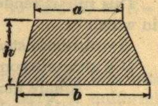


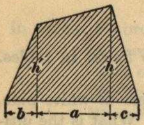

## PARALLELOGRAM

Area $= ab$

## TRAPEZOID

Area $= \frac{1}{2}\, h(a+b)$




## TRAPEZIUM

Divide into two triangles and a trapezoid.

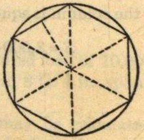
Area $= \frac{1}{2}\, bh' + \frac{1}{2}\, a(h'+h) + \frac{1}{2}\, ch$;

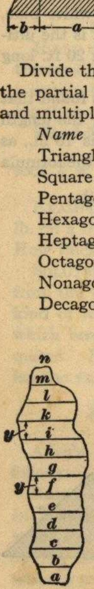
or, area $= \frac{1}{2}[bh' + ch + a(h'+h)]$

## REGULAR POLYGONS

Divide the polygon into equal triangles and find the sum of the partial areas. Otherwise, square the length of one side and multiply by proper number from the following table:

| *Name* | *No. Sides* | *Multiplier* |
|---|---|---|
| Triangle.......... | 3 | .433 |
| Square............ | 4 | 1.000 |
| Pentagon......... | 5 | 1.720 |
| Hexagon.......... | 6 | 2.598 |
| Heptagon......... | 7 | 3.634 |
| Octagon.......... | 8 | 4.828 |
| Nonagon.......... | 9 | 6.182 |
| Decagon.......... | 10 | 7.694 |






## IRREGULAR AREAS

Divide the area into trapezoids, triangles, parts of circles, etc., and find the sum of the partial areas. If the figure is very irregular, the approximate area may be found as follows: Divide the figure into trapezoids by equidistant parallel lines $b$, $c$, $d$, etc. The lengths of these lines being measured, then, calling $a$ the first and $n$ the last length, and $y$ the width of strips,

$$\text{Area} = y\left(\frac{a+n}{2} + b + c + \text{etc.} + m\right)$$

## CIRCLE

$A$ = area;

$\pi(pi) = 3.1416$;

$\frac{\pi}{4} = .7854$;

$p$ = perimeter or circumference;

$p = \pi d = 3.1416\,d$;

$p = 3\frac{1}{7}\,d$ (approximately);

$p = 2\,\pi r = 6.2832\,r$;

$d = \frac{p}{\pi} = \frac{p}{3.1416}$

$d = \frac{7}{22}p$ (approximately);

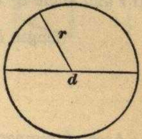
$d = 1.128\sqrt{A}$;

$r = \frac{p}{2\,\pi} = \frac{p}{6.2832}$;

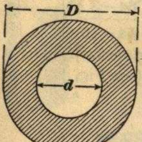
$r = .5642\sqrt{A}$;

$A = \frac{\pi d^2}{4} = .7854\,d^2$;

$A = \pi r^2 = 3.1416\,r^2$.




Side of square of area equal to circle = $.8862\,d$.




Diameter of circle of area equal to a given square = $1.128 \times$ side.

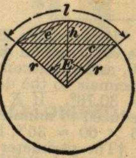
## RING

Area = $.7854(D^2 - d^2)$

## SECTOR

If radius $r$ and rise $h$ are known,

chord $c = 2\sqrt{2\,hr - h^2}$.




If chord $c$ and rise $h$ are known,

radius $r = \frac{c^2 + 4h^2}{8\,h}$

Approximately, $r = \frac{c^2}{8\,h}$

Subchord $e = \frac{1}{2}\sqrt{c^2 + 4\,h^2}$

If $h$ is not more than .4 $c$, length of arc $l = \dfrac{8e-c}{3}$, nearly

If $l$ and $r$ are known,

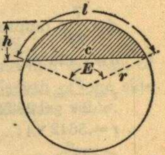
$$\text{Angle } E^* = 57.296\frac{l}{r}, = 57.3\ \frac{l}{r}, \text{ nearly}$$

$$\text{Area} = \tfrac{1}{2}\ lr$$

If $r$ and angle $E^*$ are known,

$$\text{length } l = \frac{Er}{57.296} = \frac{Er}{57.3}, \text{ (nearly)} = .0175\ Er.$$

$$\text{Area} = .0087\ r^2E$$




## SEGMENT

Area of segment = area of sector − area of triangle.

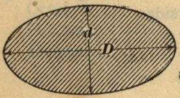
Height of triangle = $r-h$

If $l$, $r$, $c$, and $h$ are known,

$$\text{Area} = \tfrac{1}{2}\ lr - \tfrac{1}{2}\ c(r-h)$$

If $c$, $h$, $r$, and $E$ are known, find $l$ as shown under *Sector;* the area may then be found by the preceding formula.

## ELLIPSE




$$p = \pi\left(\frac{D+d}{2}\right)\frac{64-3\ q^4}{64-16\ q^2}\dagger$$

In which $p$ = the perimeter, $D$ and $d$ are the two diameters (see Fig. 12), and

$$q = \frac{D-d}{D+d}$$

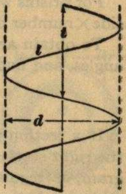
$$\text{Area} = .7854\ Dd$$

---

*If the angle $E$ contains minutes and seconds, these must be expressed in decimals of a degree. Divide the minutes by 60, and the seconds (if any) by 3,600, and add the sum of the decimals to the degrees; thus, $30° 45' 36'' = 30° + \frac{45}{60} + \frac{36}{3600} = 30.76°$. If $E$ is given in degrees and decimals, it may be reduced to minutes and seconds thus: $.76° = .76 \times 60 = 45.6'$; $.6 \times 60 = 36''$; hence, $30.76° = 30° 45' 36''$.

†The perimeter of an ellipse cannot be exactly determined, and this formula is merely an approximation giving very close results.

## HELIX




$d$ = diameter of helix;
$l$ = length of one turn of helix;
$t$ = pitch, or rise in one turn;
$n$ = number of turns;
$\pi^2 = 9.8696$;

$$l = \sqrt{\pi^2 d^2 + t^2}$$
$$t = \sqrt{l^2 - \pi^2 d^2}$$

Total length $= nl = n\sqrt{\pi^2 d^2 + t^2}$

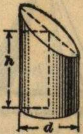
## MEANING OF SYMBOLS

$C$ = convex surface;
$S$ = whole surface;
$= C +$ area of end or ends;
$A$ = area larger base or end;
$a$ = area smaller base or end;
$P$ = perimeter of larger base;
$p$ = perimeter of smaller base;
$D$ = larger diameter;
$d$ = smaller diameter;
$V$ = volume of solid.
In a cylinder or prism,
$A = a$, $P = p$, and $D = d$

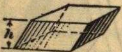

## CYLINDER

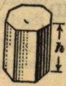
$C = Ph = 3.1416\ dh$
$S = 3.1416\ dh + 1.5708\ d^2h$
$V = Ah = .7854\ d^2h$

## FRUSTUM OF CYLINDER




$h = \frac{1}{2}$ sum of greatest and least heights
$C = Ph = 3.1416\ dh$
$S = 3.1416\ dh + .7854\ d^2 +$ area of elliptic top
$V = Ah = .7854\ d^2h$



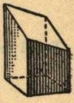

## PRISM OR PARALLELOPIPED

$C = Ph$
$S = Ph + 2A$
$V = Ah$

For prisms with regular polygons as bases, $P$ = length of one side $\times$ number of sides.

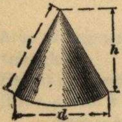
To obtain area of base, if it is a polygon, divide it into triangles, and find sum of partial areas.

## FRUSTUM OF PRISM



If a section perpendicular to the edges, called the right section, is a triangle, square, parallelogram, or regular polygon,

$$V=\frac{\text{sum of lengths of edges}}{\text{number of edges}}\times\text{area of right section}$$

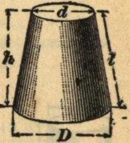



## CONE

$C=\frac{1}{2}\,Pl=1.5708\,dl$

$S=1.5708\,dl+.7854\,d^2$

$V=\dfrac{Ah}{3}=.2618\,d^2h$

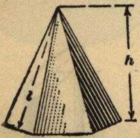



## FRUSTUM OF CONE

$C=\frac{1}{2}\,l(P+p)=1.5708\,l(D+d)$

$S=1.5708\,l(D+d)+.7854(D^2+d^2)$

$V=.2618\,h(D^2+Dd+d^2)$




## PYRAMID

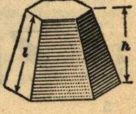
$C=\frac{1}{2}\,Pl$

$S=\frac{1}{2}\,Pl+A$

$V=\dfrac{Ah}{3}$

To obtain area of base, divide it into triangles, and find sum of their areas.

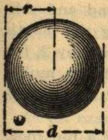
## FRUSTUM OF PYRAMID




$C=\frac{1}{2}\,l(P+p)$

$S=\frac{1}{2}\,l(P+p)+A+a$

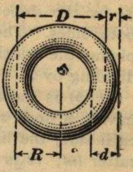
$V=\frac{1}{3}\,h\left(A+a+\sqrt{Aa}\right)$




**SPHERE**

$S = 3.1416\, d^2 = 12.5664\, r^2$

$V = .5236\, d^3 = 4.1888\, r^3$



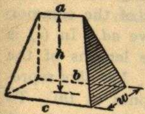

**CIRCULAR RING**

$D$ = mean diameter;

$R$ = mean radius.

$S = 4\,\pi^2 Rr = 9.8696\, Dd$

$V = 2\,\pi^2 Rr^2 = 2.4674\, Dd^2$

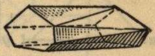



**WEDGE**

$V = \frac{1}{6}\, wh(a+b+c)$

**PRISMOID**

A *prismoid* is a solid having two parallel plane ends, the edges of which are connected by plane triangular or quadrilateral surfaces.



$A$ = area one end;
$a$ = area of other end;
$m$ = area of section midway between ends;
$l$ = perpendicular distance between ends;

$$V = \frac{1}{6}\, l(A + a + 4m)$$

The area $m$ is not in general a mean between the areas of the two ends, but its sides are means between the corresponding lengths of the ends.

$$\text{Approximately, } V = \frac{A+a}{2}\, l$$

## ROOF MENSURATION

Although the ordinary principles of mensuration are all that are necessary in calculating any roof area, the modern house, with its numerous gables and irregular surfaces, introduces complications that render some further explanation of roof measurement desirable. The most common error made in figuring roofs, which should be carefully avoided, is that of using the apparent length of slopes, as shown by the plan or side elevation, instead of the true length, obtained from the end elevations.

The area of a plain gable roof, as shown in end and side elevations in Fig. 1 (*a*), is found by multiplying the length *gj* by the slope length *bd*, and further multiplying by 2, for both sides. The area of each gable is found by multiplying the width of the gable *ad* by the altitude *cb* and dividing by 2.

In (*b*) is shown the plan and the elevation of a hip roof, having a deck *z*. The pitch of the roof being the same on each side, the line *cd* shows the true length of the commor rafter *lm*; *ce* is the height of the deck above *ad*. In (*c*) is shown the method of determining the true lengths of the hips, and the true size of one side of the roof. Let *abcd* represent the same lines as the corresponding ones in (*b*). To the line *ad*, through *b* and *c*, draw perpendiculars, as *gh* and *ef;* lay off from *g* and *e* on these lines the length of the common

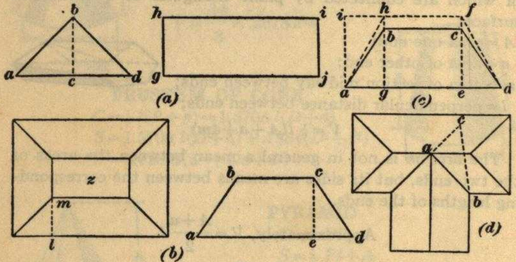



FIG. 1

rafter *ab*, in (*b*), and draw the lines *ah* and *df;* then the figure *ahfd* will show the true shape and size of that side of the roof shown in the elevation in (*b*). The triangle *def* equals in area the triangle *agh* or a similar triangle *aih*. Hence, the portion of the roof *ahfd* is equal in area to the rectangle *aife*, whose length is one-half the sum of the eaves and deck lengths, and whose breadth is the length of a common rafter.

A method of obtaining the lengths of valleys—and which is also applicable to hip rafters—is shown in (*d*), which

is the plan of a hip-and-gable roof. To ascertain the length of the valley rafter *ab*, draw the line *ac* perpendicular to the line *ab* and equal in length to the altitude of the gable; then draw the line *cb*, which will be the length required.

As an example of roof mensuration, the number of square feet of surface on the roof shown in Fig. 2 will be calculated. The area of the triangular portion *acb* is equal to one-half the base, *ab*, multiplied by the slope length of *cd*. The latter

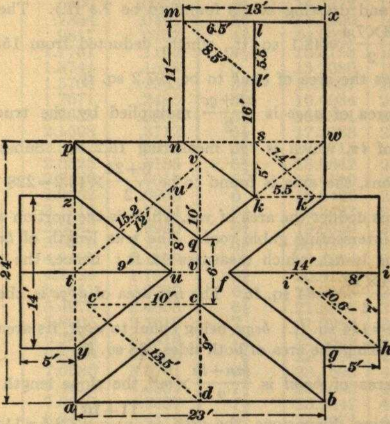



FIG. 2

is found by making *cc'*, perpendicular to *dc*, equal to the height of the ridge (10 ft.) above *ab*, and drawing *c'd*, which is the required slope length. Using dimensions, the area of *acb* is $\frac{23 \times 13.5}{2} = 155.3$ sq. ft.

The area of the trapezoid *gfih* is one-half the sum of *fi* and *gh*, multiplied by the true length of *hi*, which, by laying off *ii'*, 8 ft. along *fi*, and drawing *i'h*, is found to be 10.6 ft

Then $gfih = \frac{14+5}{2} \times 10.6 = 100.7$ sq. ft.; or, for the two slopes of the gable, the area is 201.4 sq. ft. As the opposite gable is the same size, the area of the two is $201.4 \times 2 = 402.8$ sq. ft.

The area of *qpnk* is equal to the area *qpw*, minus the area *knw*, which is covered by the intersecting gable roof. The area *qpw* is equal to the area *acb*, or 155.3 sq. ft. The area of *knw* is equal to one-half the product of *nw* and the slope of *sk* (which, by laying off *kk'* equal to the height of the gable, 5.5 ft., and drawing *sk'*, is found to be 7.4 ft.). Then area $knw = \frac{13 \times 7.4}{2} = 48.1$ sq. ft., which, deducted from 155.3 sq. ft., shows the area of *qpnk* to be 107.2 sq. ft.

The area of *apqc* is $\frac{ap+qc}{2}$ multiplied by the true slope length of *tv*, which is *tv'*, measuring 15.2 ft. Substituting dimensions, the area is found to be $\frac{6+24}{2} \times 15.2 = 228$ sq. ft. From this deduct the area of *yzu*, which is the portion covered by the intersecting gable roof. The true length of *tu* along the slope is *tu'*, which measures 12 ft.; hence, the area of *yzu* is $\frac{14 \times 12}{2} = 84$ sq. ft. The net area of *apqc* is, therefore, $228 - 84 = 144$ sq. ft.; *bcqw* being equal to *apqc*, its area is the same, making the area of both sides 288 sq. ft.

The area of *knml* is $\frac{mn+lk}{2} \times ml'$, the slope length of *ml*. Substituting dimensions, the area is $\frac{11+16}{2} \times 8.5 = 114.8$ sq. ft. As *klxw* is equal to *knml*, the area of both is 229.6 sq. ft. Adding the partial areas thus obtained, the sum is $155.3 + 402.8 + 107.2 + 288 + 229.6 = 1{,}182.9$ sq. ft., or 11.9 squares.

## CIRCUMFERENCES AND AREAS OF CIRCLES

The following table gives the diameter, the circumference, or the area when either of the other values is known. Thus, the diameter of a circle having an area of 7,200 sq. in. is, approximately, 95¾ in. and its circumference, nearly 301 in.

## CIRCUMFERENCES AND AREAS OF CIRCLES FROM 1-64 TO 100

| Diam. | Circum. | Area | Diam. | Circum. | Area |
|---|---|---|---|---|---|
| 1/64 | .0491 | .0002 | 4 | 12.5664 | 12.5664 |
| 1/32 | .0982 | .0008 | 4 1/8 | 12.9591 | 13.3641 |
| 1/16 | .1963 | .0031 | 4 1/4 | 13.3518 | 14.1863 |
| 1/8 | .3927 | .0123 | 4 3/8 | 13.7445 | 15.0330 |
| 3/16 | .5890 | .0276 | 4 1/2 | 14.1372 | 15.9043 |
| 1/4 | .7854 | .0491 | 4 5/8 | 14.5299 | 16.8002 |
| 5/16 | .9817 | .0767 | 4 3/4 | 14.9226 | 17.7206 |
| 3/8 | 1.1781 | .1104 | 4 7/8 | 15.3153 | 18.6555 |
| 7/16 | 1.3744 | .1503 | 5 | 15.7080 | 19.6350 |
| 1/2 | 1.5708 | .1963 | 5 1/8 | 16.1007 | 20.6290 |
| 9/16 | 1.7671 | .2485 | 5 1/4 | 16.4934 | 21.6476 |
| 5/8 | 1.9635 | .3068 | 5 3/8 | 16.8861 | 22.6907 |
| 11/16 | 2.1598 | .3712 | 5 1/2 | 17.2788 | 23.7583 |
| 3/4 | 2.3562 | .4418 | 5 5/8 | 17.6715 | 24.8505 |
| 13/16 | 2.5525 | .5185 | 5 3/4 | 18.0642 | 25.9673 |
| 7/8 | 2.7489 | .6013 | 5 7/8 | 18.4569 | 27.1086 |
| 15/16 | 2.9452 | .6903 | 6 | 18.8496 | 28.2744 |
| 1 | 3.1416 | .7854 | 6 1/8 | 19.2423 | 29.4648 |
| 1 1/8 | 3.5343 | .9940 | 6 1/4 | 19.6350 | 30.6797 |
| 1 1/4 | 3.9270 | 1.2272 | 6 3/8 | 20.0277 | 31.9191 |
| 1 3/8 | 4.3197 | 1.4849 | 6 1/2 | 20.4204 | 33.1831 |
| 1 1/2 | 4.7124 | 1.7671 | 6 5/8 | 20.8131 | 34.4717 |
| 1 5/8 | 5.1051 | 2.0739 | 6 3/4 | 21.2058 | 35.7848 |
| 1 3/4 | 5.4978 | 2.4053 | 6 7/8 | 21.5985 | 37.1224 |
| 1 7/8 | 5.8905 | 2.7612 | 7 | 21.9912 | 38.4846 |
| 2 | 6.2832 | 3.1416 | 7 1/8 | 22.3839 | 39.8713 |
| 2 1/8 | 6.6759 | 3.5466 | 7 1/4 | 22.7766 | 41.2826 |
| 2 1/4 | 7.0686 | 3.9761 | 7 3/8 | 23.1693 | 42.7184 |
| 2 3/8 | 7.4613 | 4.4301 | 7 1/2 | 23.5620 | 44.1787 |
| 2 1/2 | 7.8540 | 4.9087 | 7 5/8 | 23.9547 | 45.6636 |
| 2 5/8 | 8.2467 | 5.4119 | 7 3/4 | 24.3474 | 47.1731 |
| 2 3/4 | 8.6394 | 5.9396 | 7 7/8 | 24.7401 | 48.7071 |
| 2 7/8 | 9.0321 | 6.4918 | 8 | 25.1328 | 50.2656 |
| 3 | 9.4248 | 7.0686 | 8 1/8 | 25.5255 | 51.8487 |
| 3 1/8 | 9.8175 | 7.6699 | 8 1/4 | 25.9182 | 53.4563 |
| 3 1/4 | 10.2102 | 8.2958 | 8 3/8 | 26.3109 | 55.0884 |
| 3 3/8 | 10.6029 | 8.9462 | 8 1/2 | 26.7036 | 56.7451 |
| 3 1/2 | 10.9956 | 9.6211 | 8 5/8 | 27.0963 | 58.4264 |
| 3 5/8 | 11.3883 | 10.3206 | 8 3/4 | 27.4890 | 60.1322 |
| 3 3/4 | 11.7810 | 11.0447 | 8 7/8 | 27.8817 | 61.8625 |
| 3 7/8 | 12.1737 | 11.7933 | 9 | 28.2744 | 63.6174 |

TABLE—(*Continued*)

| Diam. | Circum. | Area | Diam. | Circum. | Area |
|---|---|---|---|---|---|
| 9⅛ | 28.6671 | 65.3968 | 19½ | 61.2612 | 298.648 |
| 9¼ | 29.0598 | 67.2008 | 19¾ | 62.0466 | 306.355 |
| 9⅜ | 29.4525 | 69.0293 | 20 | 62.8320 | 314.160 |
| 9½ | 29.8452 | 70.8823 | 20¼ | 63.6174 | 322.063 |
| 9⅝ | 30.2379 | 72.7599 | 20½ | 64.4028 | 330.064 |
| 9¾ | 30.6306 | 74.6621 | 20¾ | 65.1882 | 338.164 |
| 9⅞ | 31.0233 | 76.589 | 21 | 65.9736 | 346.361 |
| 10 | 31.4160 | 78.540 | 21¼ | 66.7590 | 354.657 |
| 10¼ | 32.2014 | 82.516 | 21½ | 67.5444 | 363.051 |
| 10½ | 32.9868 | 86.590 | 21¾ | 68.3298 | 371.543 |
| 10¾ | 33.7722 | 90.763 | 22 | 69.1152 | 380.134 |
| 11 | 34.5576 | 95.033 | 22¼ | 69.9006 | 388.822 |
| 11¼ | 35.3430 | 99.402 | 22½ | 70.6860 | 397.609 |
| 11½ | 36.1284 | 103.869 | 22¾ | 71.4714 | 406.494 |
| 11¾ | 36.9138 | 108.434 | 23 | 72.2568 | 415.477 |
| 12 | 37.6992 | 113.098 | 23¼ | 73.0422 | 424.558 |
| 12¼ | 38.4846 | 117.859 | 23½ | 73.8276 | 433.737 |
| 12½ | 39.2700 | 122.719 | 23¾ | 74.6130 | 443.015 |
| 12¾ | 40.0554 | 127.677 | 24 | 75.3984 | 452.390 |
| 13 | 40.8408 | 132.733 | 24¼ | 76.1838 | 461.864 |
| 13¼ | 41.6262 | 137.887 | 24½ | 76.9692 | 471.436 |
| 13½ | 42.4116 | 143.139 | 24¾ | 77.7546 | 481.107 |
| 13¾ | 43.1970 | 148.490 | 25 | 78.5400 | 490.875 |
| 14 | 43.9824 | 153.938 | 25¼ | 79.3254 | 500.742 |
| 14¼ | 44.7678 | 159.485 | 25½ | 80.1108 | 510.706 |
| 14½ | 45.5532 | 165.130 | 25¾ | 80.8962 | 520.769 |
| 14¾ | 46.3386 | 170.874 | 26 | 81.6816 | 530.930 |
| 15 | 47.1240 | 176.715 | 26¼ | 82.4670 | 541.190 |
| 15¼ | 47.9094 | 182.655 | 26½ | 83.2524 | 551.547 |
| 15½ | 48.6948 | 188.692 | 26¾ | 84.0378 | 562.003 |
| 15¾ | 49.4802 | 194.828 | 27 | 84.8232 | 572.557 |
| 16 | 50.2656 | 201.062 | 27¼ | 85.6086 | 583.209 |
| 16¼ | 51.0510 | 207.395 | 27½ | 86.3940 | 593.959 |
| 16½ | 51.8364 | 213.825 | 27¾ | 87.1794 | 604.807 |
| 16¾ | 52.6218 | 220.354 | 28 | 87.9648 | 615.754 |
| 17 | 53.4072 | 226.981 | 28¼ | 88.7502 | 626.798 |
| 17¼ | 54.1926 | 233.706 | 28½ | 89.5356 | 637.941 |
| 17½ | 54.9780 | 240.529 | 28¾ | 90.3210 | 649.182 |
| 17¾ | 55.7634 | 247.450 | 29 | 91.1064 | 660.521 |
| 18 | 56.5488 | 254.470 | 29¼ | 91.8918 | 671.959 |
| 18¼ | 57.3342 | 261.587 | 29½ | 92.6772 | 683.494 |
| 18½ | 58.1196 | 268.803 | 29¾ | 93.4626 | 695.128 |
| 18¾ | 58.9050 | 276.117 | 30 | 94.2480 | 706.860 |
| 19 | 59.6904 | 283.529 | 30¼ | 95.0334 | 718.690 |
| 19¼ | 60.4758 | 291.040 | 30½ | 95.8188 | 730.618 |

TABLE—(*Continued*)

| Diam. | Circum. | Area | Diam. | Circum. | Area |
|---|---|---|---|---|---|
| 30¾ | 96.6042 | 742.645 | 42 | 131.947 | 1,385.45 |
| 31 | 97.3896 | 754.769 | 42¼ | 132.733 | 1,401.99 |
| 31¼ | 98.1750 | 766.992 | 42½ | 133.518 | 1,418.63 |
| 31½ | 98.9604 | 779.313 | 42¾ | 134.303 | 1,435.37 |
| 31¾ | 99.7458 | 791.732 | 43 | 135.089 | 1,452.20 |
| 32 | 100.5312 | 804.250 | 43¼ | 135.874 | 1,469.14 |
| 32¼ | 101.3166 | 816.865 | 43½ | 136.660 | 1,486.17 |
| 32½ | 102.1020 | 829.579 | 43¾ | 137.445 | 1,503.30 |
| 32¾ | 102.8874 | 842.391 | 44 | 138.230 | 1,520.53 |
| 33 | 103.673 | 855.301 | 44¼ | 139.016 | 1,537.86 |
| 33¼ | 104.458 | 868.309 | 44½ | 139.801 | 1,555.29 |
| 33½ | 105.244 | 881.415 | 44¾ | 140.587 | 1,572.81 |
| 33¾ | 106.029 | 894.620 | 45 | 141.372 | 1,590.43 |
| 34 | 106.814 | 907.922 | 45¼ | 142.157 | 1,608.16 |
| 34¼ | 107.600 | 921.323 | 45½ | 142.943 | 1,625.97 |
| 34½ | 108.385 | 934.822 | 45¾ | 143.728 | 1,643.89 |
| 34¾ | 109.171 | 948.420 | 46 | 144.514 | 1,661.91 |
| 35 | 109.956 | 962.115 | 46¼ | 145.299 | 1,680.02 |
| 35¼ | 110.741 | 975.909 | 46½ | 146.084 | 1,698.23 |
| 35½ | 111.527 | 989.800 | 46¾ | 146.870 | 1,716.54 |
| 35¾ | 112.312 | 1,003.790 | 47 | 147.655 | 1,734.95 |
| 36 | 113.098 | 1,017.878 | 47¼ | 148.441 | 1,753.45 |
| 36¼ | 113.883 | 1,032.065 | 47½ | 149.226 | 1,772.06 |
| 36½ | 114.668 | 1,046.349 | 47¾ | 150.011 | 1,790.76 |
| 36¾ | 115.454 | 1,060.732 | 48 | 150.797 | 1,809.56 |
| 37 | 116.239 | 1,075.213 | 48¼ | 151.582 | 1,828.46 |
| 37¼ | 117.025 | 1,089.792 | 48½ | 152.368 | 1,847.46 |
| 37½ | 117.810 | 1,104.469 | 48¾ | 153.153 | 1,866.55 |
| 37¾ | 118.595 | 1,119.244 | 49 | 153.938 | 1,885.75 |
| 38 | 119.381 | 1,134.118 | 49¼ | 154.724 | 1,905.04 |
| 38¼ | 120.166 | 1,149.089 | 49½ | 155.509 | 1,924.43 |
| 38½ | 120.952 | 1,164.159 | 49¾ | 156.295 | 1,943.91 |
| 38¾ | 121.737 | 1,179.327 | 50 | 157.080 | 1,963.50 |
| 39 | 122.522 | 1,194.593 | 50½ | 158.651 | 2,002.97 |
| 39¼ | 123.308 | 1,209.958 | 51 | 160.222 | 2,042.83 |
| 39½ | 124.093 | 1,225.420 | 51½ | 161.792 | 2,083.08 |
| 39¾ | 124.879 | 1,240.981 | 52 | 163.363 | 2,123.72 |
| 40 | 125.664 | 1,256.640 | 52½ | 164.934 | 2,164.76 |
| 40¼ | 126.449 | 1,272.400 | 53 | 166.505 | 2,206.19 |
| 40½ | 127.235 | 1,288.250 | 53½ | 168.076 | 2,248.01 |
| 40¾ | 128.020 | 1,304.210 | 54 | 169.646 | 2,290.23 |
| 41 | 128.806 | 1,320.260 | 54½ | 171.217 | 2,332.83 |
| 41¼ | 129.591 | 1,336.410 | 55 | 172.788 | 2,375.83 |
| 41½ | 130.376 | 1,352.660 | 55½ | 174.359 | 2,419.23 |
| 41¾ | 131.162 | 1,369.000 | 56 | 175.930 | 2,463.01 |

TABLE—(*Continued*)

| Diam. | Circum. | Area | Diam. | Circum. | Area |
|---|---|---|---|---|---|
| 56½ | 177.500 | 2,507.19 | 78½ | 246.616 | 4,839.83 |
| 57 | 179.071 | 2,551.76 | 79 | 248.186 | 4,901.68 |
| 57½ | 180.642 | 2,596.73 | 79½ | 249.757 | 4,963.92 |
| 58 | 182.213 | 2,642.09 | 80 | 251.328 | 5,026.56 |
| 58½ | 183.784 | 2,687.84 | 80½ | 252.899 | 5,089.59 |
| 59 | 185.354 | 2,733.98 | 81 | 254.470 | 5,153.01 |
| 59½ | 186.925 | 2,780.51 | 81½ | 256.040 | 5,216.82 |
| 60 | 188.496 | 2,827.44 | 82 | 257.611 | 5,281.03 |
| 60½ | 190.067 | 2,874.76 | 82½ | 259.182 | 5,345.63 |
| 61 | 191.638 | 2,922.47 | 83 | 260.753 | 5,410.62 |
| 61½ | 193.208 | 2,9[illegible]0.58 | 83½ | 262.324 | 5,476.01 |
| 62 | 194.779 | 3,019.08 | 84 | 263.894 | 5,541.78 |
| 62½ | 196.350 | 3,067.97 | 84½ | 265.465 | 5,607.95 |
| 63 | 197.921 | 3,117.25 | 85 | 267.036 | 5,674.51 |
| 63½ | 199.492 | 3,166.93 | 85½ | 268.607 | 5,741.47 |
| 64 | 201.062 | 3,217.00 | 86 | 270.178 | 5,808.82 |
| 64½ | 202.633 | 3,267.46 | 86½ | 271.748 | 5,876.56 |
| 65 | 204.204 | 3,318.31 | 87 | 273.319 | 5,944.69 |
| 65½ | 205.775 | 3,369.56 | 87½ | 274.890 | 6,013.22 |
| 66 | 207.346 | 3,421.20 | 88 | 276.461 | 6,082.14 |
| 66½ | 208.916 | 3,473.24 | 88½ | 278.032 | 6,151.45 |
| 67 | 210.487 | 3,525.66 | 89 | 279.602 | 6,221.15 |
| 67½ | 212.058 | 3,578.48 | 89½ | 281.173 | 6,291.25 |
| 68 | 213.629 | 3,631.69 | 90 | 282.744 | 6,361.74 |
| 68½ | 215.200 | 3,685.29 | 90½ | 284.315 | 6,432.62 |
| 69 | 216.770 | 3,739.29 | 91 | 285.886 | 6,503.90 |
| 69½ | 218.341 | 3,793.68 | 91½ | 287.456 | 6,575.56 |
| 70 | 219.912 | 3,848.46 | 92 | 289.027 | 6,647.63 |
| 70½ | 221.483 | 3,903.63 | 92½ | 290.598 | 6,720.08 |
| 71 | 223.054 | 3,959.20 | 93 | 292.169 | 6,792.92 |
| 71½ | 224.624 | 4,015.16 | 93½ | 293.740 | 6,866.16 |
| 72 | 226.195 | 4,071.51 | 94 | 295.310 | 6,939.79 |
| 72½ | 227.766 | 4,128.26 | 94½ | 296.881 | 7,013.82 |
| 73 | 229.337 | 4,185.40 | 95 | 298.452 | 7,088.24 |
| 73½ | 230.908 | 4,242.93 | 95½ | 300.023 | 7,163.04 |
| 74 | 232.478 | 4,300.85 | 96 | 301.594 | 7,238.25 |
| 74½ | 234.049 | 4,359.17 | 96½ | 303.164 | 7,313.84 |
| 75 | 235.620 | 4,417.87 | 97 | 304.735 | 7,389.83 |
| 75½ | 237.191 | 4,476.98 | 97½ | 306.306 | 7,466.21 |
| 76 | 238.762 | 4,536.47 | 98 | 307.877 | 7,542.98 |
| 76½ | 240.332 | 4,596.36 | 98½ | 309.448 | 7,620.15 |
| 77 | 241.903 | 4,656.64 | 99 | 311.018 | 7,697.71 |
| 77½ | 243.474 | 4,717.31 | 99½ | 312.589 | 7,775.66 |
| 78 | 245.045 | 4,778.37 | 100 | 314.160 | 7,854.00 |

# GEOMETRICAL DRAWING

## PROBLEMS

**To Erect a Perpendicular to the Line *bc* at the Point *a*.**—With *a*, Fig. 1, as a center, and any radius, as *ab*, strike arcs cutting the line at *b* and *c*. From *b* and *c* as centers, and any radius greater than *ba*, strike arcs intersecting at *d*. Draw *da*, which will be perpendicular to *bc* at *a*.

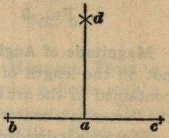


FIG. 1

**To Draw a Line Parallel to *ab*.**—At any points *a*, Fig. 2, and *b*, with a radius equal to the required distance between the lines, draw arcs at *c* and *d*. The line *cd*, tangent to the arcs, will be the required parallel.

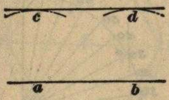


FIG. 2

**To Bisect the Angle *bac*.**—With *a*, Fig. 3, as a center, strike an arc cutting the sides of the angle in *b* and *c*. With *b* and *c* as centers, and any radius, strike arcs intersecting, as at *d*. Draw *da*, the bisector.

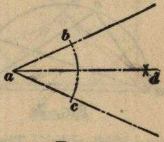


FIG. 3

**To Erect a Perpendicular at the End of a Line.**—Take a center anywhere above the line, as at *b*, Fig. 4. Strike an arc passing through *a* and cutting the given line at *c*. Draw a line through *c* and *b*, cutting the arc at *d*. Draw the line *ad*, which will be the required perpendicular.

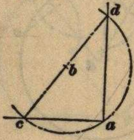


FIG 4

**To Divide a Line Into Any Number of Equal Parts.**—Let it be required to divide the line *ab*, Fig. 5, into five equal parts. Draw any line *ad*, and point off five equal divisions, as shown. From *5* draw a line to *b* and draw *4-4′*, *3-3′*, etc. parallel to *5b*.

**To Divide a Space Between Two Parallel Lines or Surfaces.**—An example of this problem is the spacing of risers in a stairway. Draw *ab* and *ce*, Fig. 5, the given distance apart. Then move a scale along them, until as many spaces are included along *ad* as there are number of divisions required. Mark the points *1*, *2*, *3*, etc. and draw lines through them parallel to *ab* and *ce*.

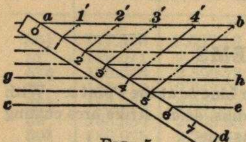



FIG. 5

**Magnitude of Angles.**—The magnitude of an angle depends not on the length of its sides, but on the number of degrees contained in the arc of a circle drawn with the vertex as a center.

The circle is divided into 360 equal parts, called *degrees*. To divide a quadrant as shown in the figure, first divide it into three parts by the arcs at *e* and *d*, Fig. 6, chords *cd* and *ae* being equal to the radius. Then subdivide with dividers.

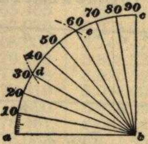



FIG. 6

An *inscribed angle* has its vertex (as *c* or *d*, Fig. 7), in the circumference of a circle. Any angle inscribed in a semicircle is a right angle, as *acb*, or *adb*.

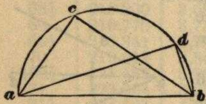



FIG. 7

**To Draw a Circle Through Three Points Not in a Straight Line as *a*, *b*, and *c*.**—Bisect *ab*, Fig. 8, and also *bc*. The two bisectors will intersect in a point *d*, which will be the center of the required circle.

**To Find the Center of a Circular Arc as *a*, *b*, *c*.**—Take a point, as *b*, Fig. 8, on the curve, and draw any two chords, *ba* and *bc*. Bisect these lines by perpendiculars; the intersection *d* of these lines will be the required center.

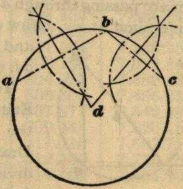



FIG. 8

**To Find a Straight Line Nearly Equal to a Semi-Circumference as** *a b c.*—On the diameter construct the equilateral triangle *each*, Fig. 9. Through the ends *a* and *c* draw *he* and *hf;* then *ef*, which is tangent to the semi-circumference and parallel to the diameter, is the length of the semi-circumference. Draw any line, as *hkl*; then *lf* is almost exactly the length of arc *kc*, and *bl* that of arc *bk*.

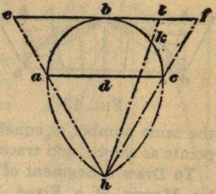


FIG. 9

**To Construct a Hexagon From a Given Side.**—Describe a circle with a radius *ab* equal to the given side. Draw a diameter as *cb*, Fig. 10. From *c* and *b* as centers, and a radius equal to the given side, draw arcs cutting the circle at *k, d, f,* and *e*. Connect *c, k, f, b, e,* and *d*.

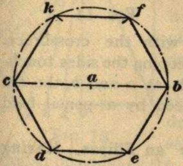


FIG. 10

**To Inscribe an Octagon in a Square.**—Draw the diagonals *ac* and *bd*, Fig. 11. With *a* as a center, and *ae* as a radius, strike an arc cutting the sides of the square at *f* and *h*. Repeat the operation at *b, c,* and *d*, and draw lines connecting the eight points thus found to form the figure required.

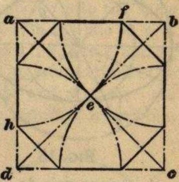


FIG. 11

**To Draw Any Regular Polygon in a Circle.**—Divide 360° by the number of sides; the quotient will be the angle *aob*, Fig. 12. Lay off this angle at the center with a protractor, and draw its chord, a side of the required polygon. Step this side around on the circumference, and connect the points found.

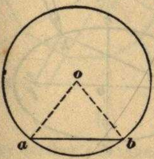


FIG. 12

**To Draw a Segment of a Circle, Having Given the Chord** *ab* **and Height**

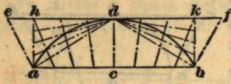



FIG. 13

*cd.*—Draw *ef*, through *d*, parallel to *ab*; also, *ad* and *db*. Draw *ae* and *bf* perpendicular to *ad* and *db*; also *ah* and *bk* perpendicular to *ab*. Divide *ed*, *df*, *ac*, *cb*, *ah*, and *bk* into the same number of equal parts. Draw lines connecting the points as shown, and trace the curve through the intersections.

**To Draw a Segment of a Circle by Means of a Fixed Triangle.** Let *ab* Fig. 14, be the required chord, and *dc* the rise. Drive nails at *a* and *b*. Make a triangle, as shown, of thin strips, so that the vertex comes at *c*, and stiffen it with the crossbrace. Now, by moving the triangle, always keeping the sides touching the nails at *a* and *b*, the arc may be traced by a pencil held at *c*.

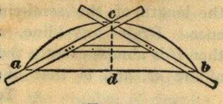



FIG. 14

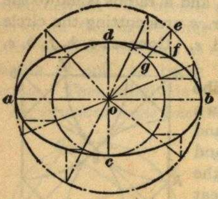



FIG. 15

**To Draw an Ellipse, Having Given the Axes.**—Draw concentric circles whose diameters are equal to the axes *ab* and *cd* Fig. 15. From *o* draw any radius as *oe*. From *g*, where *oe* cuts the inner circle, draw *gf* parallel to the major axis *ab*. From *e*, draw *ef* parallel to the minor axis *dc*. The intersection *f* gives a point on the ellipse; other points are similarly found.

**To Draw an Ellipse With a String, Having Given the Axes *ab* and *cd*.**—With *c*, Fig. 16, as a center, and a radius equal to *ob*, strike arcs cutting the major axis at *e* and *f*, the foci of the ellipse. Stick pins at *e* and *f*, and attach a string as shown, the length of the string being equal to the length

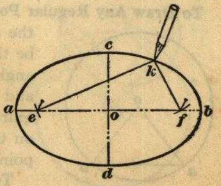



FIG. 16

of the major axis. Keep the string stretched with a pencil point, and sweep around the ellipse.

**To Draw a Parabola.**—Having given the coordinates *ab* and *bc*, Fig. 17, to draw a parabola, complete the rectangle *abcd*. Divide *bc* and *cd* into the same number of equal parts. From *1'*, *2'*, *3'*, etc., draw lines through *a*. Through *1*, *2*, *3*, etc., draw lines parallel to *ab*. The intersections of *1'a* and *1–1''*, of *2'a* and *2–2''*, etc. are points on the required parabola.

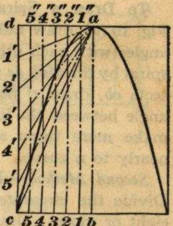



FIG. 17

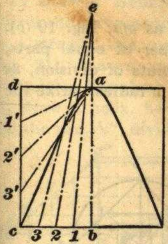
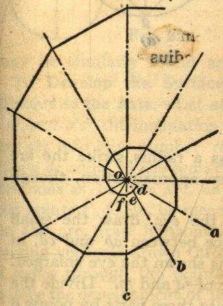


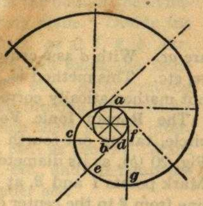

FIG. 18

**To Draw a Hyperbola.**—Having given the coordinates *ab* and *bc*, Fig. 18, to draw the curve, complete the rectangle *abcd*, and divide *bc* and *cd* into the same number of equal parts. Select any point *e* on the line *ba* prolonged; connect *1*, *2*, *3* to *e*, and *1'*, *2'*, *3'*, to *a*. The intersections of *1e* and *1'a*, of *2e* and *2'a*, etc. are points on the required hyperbola.




(*a*)

FIG. 19




(*b*)

The farther *e* is taken from *a*, the more nearly will the hyperbola approach a parabola in form.

**To Draw a Spiral.**—*First Method.*—From a point, as *o*, Fig. 19 (*a*), draw radiating lines, *oa*, *ob*, *oc*, etc., making equal angles with each other. At any point, as *d*, on *oa*, start the spiral by drawing *de* perpendicular to *oa*; from *e* where *de* intersects *ob*, draw *ef* perpendicular to *ob*; etc. By making the angle between the lines smaller, the spiral may be made to make more turns and the broken line will approach more nearly to a curve.

*Second Method.*—Draw a small circle, as *bfa*, Fig. 19 (*b*). Divide the circumference into any number of equal parts, eight or more. Draw tangents at the points of division, as *bc*, *de*, etc. With *b* as a center, and *ba* as a radius, strike the

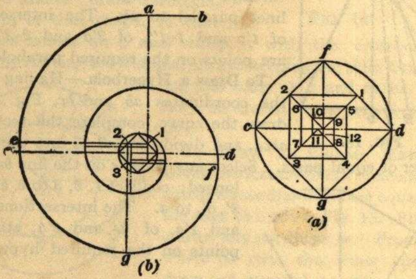



FIG. 20

arc *ac*. With *d* as a center, and *dc* as a radius, strike the arc *ce*, etc. This method is a very close approximation, though not mathematically correct.

**The Roman Ionic Volute.**—For the *eye*, draw the small circle, taking one-fourth the distance between *ab* and *cd*, in Fig. 20 (*b*), as its diameter. In (*a*) is shown the eye enlarged. Mark points *1* and *2*, at the middle of *fd* and *fc*. Divide the line from *2* to the center of the eye into three parts by points *6* and *10*. At a distance below *cd* equal to 2½ times the space between *2–1* and *6–5*, draw *3–4*. Draw the line from *1* to the center of the eye, also *10–9*, *2–3*, and *5–4*. Draw 45° lines

from *3* and *4*; draw *6–7*, *10–11*, *9–8*, *11–12*, and *7–8*. Use the points thus found as centers, *1* being the center for arc *ae*; *2* for arc *eg*; *3* for arc *gf*; etc.

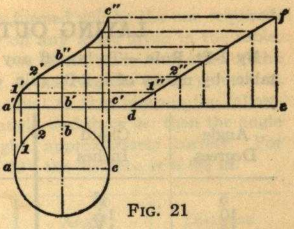



FIG. 21

**To Draw a Helix.**—A *helix* is the curve assumed by a straight line, as *df*, Fig. 21, drawn on a plane, when the plane is wrapped around a cylindrical surface. To draw a helix, having given the plan of the cylinder *abc* and the rise *c'c''*, divide the arc *abc* into any number of equal parts, as at *1*, *2*, *b*, etc. Divide the line *c'c''* into the same number of equal parts. Draw verticals through the divisions of the arc *abc*, and horizontals through the divisions of *c'c''*, intersecting in points *1'*, *2'*, *b''*, etc. Other points may be similarly found and the curve drawn.

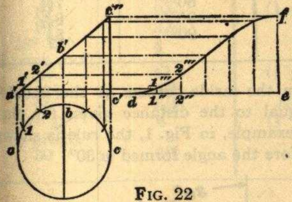



FIG. 22

**To Develop the Surface of a Cylinder Cut by a Plane Oblique to the Axis.**—Let *abc*, Fig. 22, be the plan of the cylinder, and *a'c''* the inclination of the cutting plane. Divide the arc *abc* into any number of equal parts, as at *1*, *2*, *b*, etc. Draw *de* equal to the semi-circumference, and mark the same divisions as on the arc, as *d–1''*, *1''–2''*, etc. After locating the points *1'*, *2*, etc. by means of verticals through the divisions on the arc, draw horizontal lines through these points, intersecting verticals drawn through *1''*, *2''*, etc., as shown. Trace a curve through the points *d*, *1'''*, *2'''*, etc., and the figure *dfe* will be the development of the half cylinder *abc*.

## LAYING OUT ANGLES

**By 2-Ft. Rule.**—To lay off any angle given in the following table, by means of a 2-ft. rule, open the rule at the middle

| Angle Degrees | Chord Inches | Angle Degrees | Chord Inches |
|---|---|---|---|
| 5 | $\frac{17}{32}$ | 50 | $5\frac{1}{16}$ |
| 10 | $1\frac{1}{32}$ | 55 | $5\frac{17}{32}$ |
| 15 | $1\frac{9}{16}$ | 60 | 6 |
| 20 | $2\frac{3}{32}$ | 65 | $6\frac{7}{16}$ |
| 25 | $2\frac{19}{32}$ | 70 | $6\frac{7}{8}$ |
| 30 | $3\frac{3}{32}$ | 75 | $7\frac{5}{16}$ |
| 35 | $3\frac{19}{32}$ | 80 | $7\frac{23}{32}$ |
| 40 | $4\frac{3}{32}$ | 85 | $8\frac{3}{32}$ |
| 45 | $4\frac{19}{32}$ | 90 | $8\frac{1}{2}$ |

until the distance between the inside corners at the knuckle joint (6-in. mark) is equal to the distance given for that angle under *Chord*. For example, in Fig. 1, the rule is shown to be open $3\frac{3}{32}$ in., therefore the angle formed is 30°

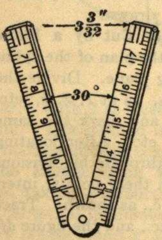



FIG. 1

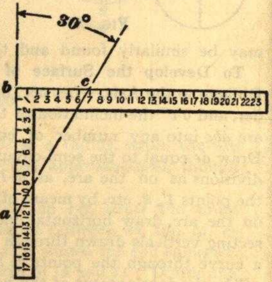



FIG. 2

To lay off an angle greater than 90°, subtract the angle from 180°; lay out the latter angle, extending one side past

the vertex; the greater angle formed will be the one required.

**By Steel Square.**—To lay off any angle given in the table, by means of a steel square, set either blade or tongue of the square along the line *ab*, Fig. 2, marking the 12 in. point at *a*. Mark *c* at a distance from *b* equal to that given in the following table for the required angle, and draw *ac*; then the angle *bac* will be the angle sought, approximately correct. For example, to find an angle of 30°, the distance *bc* is $6\frac{15}{16}$ in.

| Angle Degrees | Distance Inches | Angle Degrees | Distance Inches |
|---|---|---|---|
| 5 | $1\frac{1}{16}$ | 33° 42′ ($\frac{1}{3}$ pitch) | 8 |
| 10 | $2\frac{3}{32}$ | 35 | $8\frac{13}{32}$ |
| 15 | $3\frac{7}{32}$ | 40 | $10\frac{1}{16}$ |
| 18° 25′ ($\frac{1}{6}$ pitch roof) | 4 | 45 ($\frac{1}{2}$ pitch) | 12 |
| 20 | $4\frac{3}{8}$ | 50 | $14\frac{5}{16}$ |
| $22\frac{1}{2}$ | $4\frac{31}{32}$ | 53° 7′ ($\frac{2}{3}$ pitch) | 16 |
| 25 | $5\frac{19}{32}$ | 55 | $17\frac{1}{8}$ |
| 26° 33′ ($\frac{1}{4}$ pitch) | 6 | 60 | $20\frac{25}{32}$ |
| 30 | $6\frac{15}{16}$ | | |

# STRUCTURAL DESIGN

## SPECIFIC GRAVITY

The *specific gravity* of a solid or liquid body is the ratio between its weight and that of a like volume of distilled water at 39.1° F. If the solid is of irregular shape, its specific gravity may be found by weighing it in air and in water; the loss of weight in water is the weight of an equal volume of water; hence, if $W$ is the weight in air, and $W'$ the weight in water, the specific gravity is $\frac{W}{W-W'}$.

The weight of water in various conditions is given in the following table:

*Weight per Cubic Foot in Pounds*

| | |
|---|---|
| Water, pure at 32° F | 62.417 |
| Water, pure at 39.1° F | 62.425 |
| Water, pure at 62° F | 62.355 |
| Water, pure at 212° F | 59.700 |
| Water, sea | 64.080 |
| Ice | 57.400 |
| Snow, fresh | 5 to 12 |
| Snow, wet | 15 to 50 |

## LOADS ON STRUCTURES

### DEAD LOADS

Loads on buildings may be classed under three general divisions: *dead loads, live loads,* and *snow and wind loads.*

The *dead loads* consist of the weight of the materials composing the structure. For instance, the brickwork in the

**WEIGHTS AND SPECIFIC GRAVITIES OF METALS**

| Name of Metal | Weight per Cubic Inch Pounds | Weight per Cubic Foot Pounds | Specific Gravity |
|---|---|---|---|
| Aluminum | .096 | 166 | 2.66 |
| Antimony | .242 | 418 | 6.70 |
| Bismuth | .355 | 613 | 9.82 |
| Brass, cast | .292 | 504 | 8.07 |
| Brass, rolled | .302 | 523 | 8.38 |
| Copper, cast | .319 | 550 | 8.81 |
| Copper, rolled | .321 | 555 | 8.89 |
| Gold, 24 carat | .697 | 1,204 | 19.29 |
| Iron, cast | .260 | 450 | 7.21 |
| Iron wrought | .277 | 480 | 7.69 |
| Lead, commercial | .412 | 712 | 11.41 |
| Mercury, 60° F | .490 | 846 | 13.55 |
| Silver | .378 | 655 | 10.50 |
| Steel | .283 | 490 | 7.85 |
| Tin, cast | .265 | 458 | 7.34 |
| Zinc | .253 | 437 | 7.00 |

walls forms a portion of the dead load upon the footings; the materials in the floors impose a dead load upon the columns, etc. In order to figure the amount of the dead loads on

structures and the members therein, the weight of the various materials used must be known, and the accompanying tables will be found useful.

## WEIGHTS AND SPECIFIC GRAVITIES OF BUILDING MATERIALS, ETC.

| Name of Material | Weight per Cubic Foot Pounds | Specific Gravity |
|---|---|---|
| Bluestone | 160 | 2.56 |
| Brick, pressed | 150 | 2.40 |
| Brick, common | 125 | 2.00 |
| Cement, Portland (packed) | 100–120 | 1.60–1.92 |
| Cement, Portland (loose) | 70–90 | 1.12–1.44 |
| Cement, Slag (packed) | 80–100 | 1.28–1.60 |
| Cement, Slag (loose) | 55–75 | .88–1.20 |
| Chalk | 156 | 2.50 |
| Charcoal | 15–34 | .24–.54 |
| Cinder concrete | 110 | 1.76 |
| Clay, ordinary | 120–150 | 1.92–2.40 |
| Coal, hard, solid | 93.5 | 1.50 |
| Coal, hard, broken | 54 | .867 |
| Coal, soft, solid | 84 | 1.35 |
| Coal, soft, broken | 54 | .87 |
| Coke, loose | 23–32 | .37–.51 |
| Concrete, cement, stone, or gravel | 140–155 | 2.24–2.48 |
| Earth, rammed | 90–100 | 1.44–1.60 |
| Granite | 165–170 | 2.64–2.72 |
| Gravel | 117–125 | 1.87–2.00 |
| Lime, quick (ground loose) | 53 | .85 |
| Limestones | 170 | 2.72 |
| Marble | 164 | 2.62 |
| Plaster of Paris (cast) | 80 | 1.28 |
| Sand | 90–106 | 1.44–1.70 |
| Sandstone | 151 | 2.42 |
| Shales | 162 | 2.60 |
| Slate | 160–180 | 2.56–2.88 |
| Terra cotta | 110 | 1.76 |
| Trap rock | 170 | 2.72 |

In calculating the dead loads, there are certain weights that must be assumed. For instance, the weight of the floor-beams and girders are not known, because their size has not

## WEIGHTS AND SPECIFIC GRAVITIES OF MASONRY

| Masonry | Weight per Cubic Foot Pounds | Specific Gravity |
|---|---|---|
| Common brickwork, cement mortar.. | 130 | 2.08 |
| Common brickwork, lime mortar .... | 120 | 1.92 |
| Granite or limestone rubble, dry..... | 138 | 2.21 |
| Granite or limestone rubble......... | 150 | 2.40 |
| Granite or limestone, dressed........ | 165 | 2.64 |
| Pressed brickwork................ | 140 | 2.24 |
| Sandstone rubble................ | 145 | 2.32 |
| Terra-cotta masonry.............. | 112 | 1.79 |

## WEIGHTS OF DRY WOODS

| Name of Wood | Weight per Cubic Foot Pounds | Name of Wood | Weight per Cubic Foot Pounds |
|---|---|---|---|
| *Evergreens* | | *Hardwoods* | |
| Cedar, canoe...... | 23 | Beech............ | 42 |
| Cedar, red........ | 30 | Birch, red........ | 35 |
| Cypress.......... | 29 | Chestnut......... | 28 |
| Fir, balsam....... | 23 | Cherry........... | 36 |
| Fir, red of California.......... | 29 | Elm............. | 34 |
| Fir, white........ | 22 | Gum, sweet....... | 37 |
| Hemlock......... | 26 | Hickory.......... | 51 |
| Pine, Oregon...... | 32 | Locust........... | 42 |
| Pine, long-leaf.... | 38 | Maple, hard..... .. | 43 |
| Pine, short-leaf... | 32 | Oak, red......... | 45 |
| Pine, sugar....... | 22 | Oak, white ...... | 50 |
| Pine, white....... | 24 | Poplar, yellow .... | 26 |
| Redwood, California............ | 26 | Sycamore......... | 35 |
| Spruce, black..... | 28 | Walnut, black .... | 38 |
| Spruce, Norway .. | 29 | *Rare Woods* | |
| Spruce, Sitka..... | 26 | Boxwood......... | 50 |
| Spruce, white..... | 25 | Ebony........... | 76 |
| *Hardwoods* | | Mahogany........ | 32–60 |
| Ash, black........ | 39 | Rosewood........ | 68 |
| Ash, white........ | 39 | Teak............ | 50 |
| Basswood......... | 28 | Walnut, Circassian | 35 |
| | | Walnut, Persian.. | 36 |

## APPROXIMATE WEIGHT OF BUILDING MATERIALS

| Material | Average Weight Pounds per Square Foot |
|---|---|
| Corrugated galvanized iron, No. 20, unboarded | $2\frac{1}{4}$ |
| Copper, 16 oz., standing seam | $1\frac{1}{4}$ |
| Felt and asphalt, without sheathing | 2 to 3 |
| Glass, $\frac{1}{8}$ in. thick | $1\frac{3}{4}$ |
| Hemlock sheathing, 1 in. thick | $2\frac{1}{2}$ |
| Lead, about $\frac{1}{8}$ in. thick | 6 to 8 |
| Lath-and-plaster ceiling (ordinary) | 6 to 8 |
| Mackite, 1 in. thick, with plaster | 10 |
| Neponset roofing felt, two layers | $\frac{1}{2}$ |
| Spruce sheathing, 1 in. thick | 2 |
| Slate, $\frac{3}{16}$ in. thick, 3 in. double lap | $6\frac{3}{4}$ |
| Slate, $\frac{1}{8}$ in. thick, 3 in. double lap | $4\frac{1}{2}$ |
| Shingles, $6'' \times 18''$, one-third to weather | 2 |
| Skylight of glass, $\frac{3}{16}$ to $\frac{1}{2}$ in., including frame | 4 to 10 |
| Slag roof, 4-ply | 4 |
| Tin, IX | $\frac{3}{4}$ |
| Tiles (plain), $10\frac{1}{2}'' \times 6\frac{1}{4}'' \times \frac{5}{8}''$—$5\frac{1}{4}''$ to weather | 18 |
| Tiles (Spanish), $14\frac{1}{2}'' \times 10\frac{1}{2}''$—$7\frac{1}{4}''$ to weather | $8\frac{1}{2}$ |
| White-pine sheathing, 1 in. thick | $2\frac{1}{2}$ |
| Yellow-pine sheathing, 1 in. thick | 4 |

as yet been determined; likewise, the dimensions of the columns and many other structural details are unknown. The assumed

## WEIGHT OF TERRA-COTTA TILE

| Kind | Span Feet | Thickness Inches | Weight Pounds per Square Foot |
|---|---|---|---|
| Dense-tile flat arch | 4 to 7 | 6 to 12 | 22 to 42 |
| Dense-tile partition | | 3 to 6 | 15 to 24 |
| Porous-tile partition | | 3 to 6 | 17 to 26 |
| Porous-tile ceiling | | 2 to 4 | 12 to 20 |
| Porous-tile roofing | | 2 to 4 | 12 to 22 |

weights are obtained by approximating the dimensions of the parts of the structure and estimating their weights. After

the structure has been designed, the actual dead loads should be checked, to make sure they approximate closely to those assumed. If any considerable variation is found, it can be

**WEIGHTS OF FLOORS, PARTITIONS, AND ROOFS**

| Description | Pounds per Square Foot |
|---|---|
| *Floors, Including Weight of Beams* | |
| Wooden, 2″×10″ joists, 1 floor, plaster ceiling | 11 to 14 |
| Wooden, 2″×12″ joists, 2 floors, plaster ceiling | 14 to 17 |
| Hollow tile, end or side construction, 2 floors, ceiling | 55 to 70 |
| Hollow tile, segmental, 6-in. to 8-in. tile, 1 floor, ceiling on arch | 60 to 70 |
| Hollow tile, herculean, 6-in. to 12-in., 1 floor, ceiling | 60 to 85 |
| Hollow tile, Johnson, 4-in. to 12-in. tile, 2 floors, ceiling | 65 to 90 |
| Brick-arch, 4-in. and 8-in., 1 floor, ceiling | 75 to 115 |
| Concrete slabs, top slab, 2 floors, ceiling, hung | 65 to 90 |
| Concrete slabs, bottom slab, 2 floors, ceiling | 70 to 115 |
| *Partitions, Plastered Both Sides* | |
| Stud, 4-in. | 15 to 20 |
| Terra cotta, 3-in. blocks | 25 to 27 |
| Terra cotta, 4-in. blocks | 26 to 28 |
| Terra cotta, 5-in. blocks | 34 to 36 |
| Gypsum, 3-in. blocks | 18 |
| Gypsum, 4-in. blocks | 20 |
| Gypsum, 6-in. blocks | 25 |
| *Roofs, Including Weight of Rafters* | |
| Shingles, on lath and wooden rafters | 6 to 10 |
| Tin on boards and felt and wood rafters | 6 to 8 |
| Slate on lath and wood rafters | 10 to 15 |
| Tar and gravel on boards and wood rafters | 10 to 14 |
| Corrugated iron and wood rafters | 4 to 6 |
| Tile on felt and boards and wood rafters | 15 to 22 |

NOTE.—If roofs are lathed and plastered on the underside of rafters, add 6 lb. per sq. ft. to the weight given. If the ceiling is hung from the rafters or floor beams on wood or metal framing, add 9 to 10 lb. per sq. ft.

taken care of by increasing or diminishing the sizes already determined.

**Weight of Fireproof Floors.**—In figuring the dead load for any system of floor construction, it is necessary to calculate

carefully the total weight of the elements composing the system, which are the arches, filling, flooring, ceiling, and the steel construction. The weight of fixed or permanent partitions should always be taken into account, and the beams, etc. carrying them, proportioned accordingly. Where the partitions are movable, an additional weight of, say, 20 lb. per sq. ft., should be added to the dead load on the entire floor area.

Where only the approximate dead load due to the floor, partition, or roof construction is desired, the preceding table will be of use. In this table, the wooden floors and roof sheathing are taken as $\frac{7}{8}$ in. thick; cinder fill is estimated at 60 lb. per cu. ft.; and cinder concrete, at 110 lb. per cu. ft.

## LIVE LOADS

The *live load* is variable, and consists of the weight of people, furniture, stocks of goods, machinery, etc. The amount of this load, which should be added to the dead load, depends on the use to which the building is to be put. Where the floor is required to support a considerable live load, concentrated

### LIVE LOADS OF BUILDINGS

| Type of Building | Pounds per Square Foot |
|---|---|
| Dwellings, offices, hotels, and apartment houses | 40 to 70 |
| Theaters, churches, ballrooms, and drill halls | 80 to 120 |
| Factories | 150 up |
| Warehouses | 150 to 250 up |

at a particular place, such as a heavy safe or piece of machinery, special provision should be made in the floor construction for it. The preceding table gives the live loads per square foot sometimes used in building construction, although the decision in each individual case depends on local conditions and the experience of the designer.

A live load of 70 lb. per sq. ft. will seldom be attained in dwellings; but, as city houses are liable to be used for other

than dwelling purposes, it is not generally advisable to use a lighter load. In country houses, hotels, etc., where economy demands it, and the intended use for a long time is certain, a live load of 40 lb. per sq. ft. of floor surface is ample for all rooms not used for public assembly. For such rooms, a live load of 80 lb. per sq. ft. will usually be sufficient, as experience shows that a floor is not apt to be crowded with a greater weight than this. If the desks and chairs are fixed, as in a schoolroom or church, a live load over 40 to 50 lb. will never be attained.

Office-building floors have been designed for a live load ranging from 20 to 150 lb. per sq. ft., but a conservative practice is to use about 70 lb. per sq. ft. An investigation of the live loads in over 200 office buildings in Boston showed that the greatest live load in any office was 40 lb. per sq. ft., and the 10 heaviest loaded offices averaged 33 lb. per sq. ft., the average live load for the entire number of offices being about 17 lb. per sq. ft.

Retail stores should have floors proportioned for a live load of 100 lb. and upwards; and, for wholesale stores, machine shops, etc., a live load of at least 150 lb. per sq. ft. should be figured on. The static load in factories seldom exceeds 40 to 50 lb. per sq. ft. of floor surface, and usually a live load of 100 lb., including the effect of vibrations due to moving machinery, is ample. The conservative rule is, in general, to assume loads not less than the foregoing, and to be sure that the beams are proportioned to avoid excessive deflection. Stiffness is as important a factor as mere strength.

In designing the floors of office buildings, or buildings of like character, it is good practice to figure the full live load on the floor joists or beams, but to consider only a certain percentage as coming upon the girders, columns, and foundations, on the assumption that all of the floors will not be fully loaded at the same time. This percentage should be carefully considered in each case; and the amounts will depend on the height of the building in question and the judgment of the designer.

In proportioning the foundations of hotels, office buildings, etc., the live load may be neglected, but should be considered in heavy warehouses. In buildings carrying heavy machinery

causing much vibration, it is good practice to double the estimated live load.

## SNOW AND WIND LOADS

**Snow Loads.**—Data in regard to snow and wind loads are necessary in connection with the design of roof trusses. Snow loads are generally estimated in pounds per square foot of horizontal projection of roof, and as acting in a vertical direction. For slopes of 20° and under, a snow load of 25 lb. per sq. ft. of horizontal projection of roof is a safe allowance. This load may be reduced 1 lb. for each additional degree of increase in the slope of the roof. When snow guards are used, the reduction should be only ¾ lb. for each additional degree of rise over 20°. When the pitch is 45° or over, the snow load may be neglected, if snow guards are not used, as the action of the wind, together with the slope of the roof prevent the accumulation of snow. Snow loads naturally vary with the climate and latitude. The maximum allowances that may be made in different localities in the United States are given in the following table.

### MAXIMUM ALLOWANCE FOR SNOW LOADS

| Locality | Pounds per Square Foot |
|---|---|
| Southern States and Pacific Slope | 5 |
| Baltimore, Cincinnati, and St. Louis | 10 |
| Philadelphia, Pittsburg, and Wheeling | 15 |
| New York City, Chicago, and Cleveland | 20 |
| Boston, Albany, Buffalo, and St. Paul | 25 |
| Northern New England, Michigan, and Minnesota | 30 |

**Wind Loads.**—The wind is considered as blowing in a horizontal direction, but the resulting pressure on the roof is generally taken normal (at right angles) to the slope. The greatest wind velocity recorded in the United States is 100 mi. per hr. Calculations show that a wind of that force will exert a pressure against a vertical surface of about 50 lb. per sq. ft., but in

practice 40 lb. per sq. ft. is taken as the maximum. The following table shows the pressures exerted against a vertical plane surface by the wind at different velocities.

The wind pressure upon a cylindrical surface is one-half that upon a flat surface of the same height and width. As the wind is considered as traveling in a horizontal direction, it is evident that the more nearly vertical the slope of the roof, the greater

**TABLE OF WIND PRESSURES**

| Strength of Winds | Miles per Hour | Feet per Minute | Feet per Second | Force, in Pounds per Square Foot |
|---|---|---|---|---|
| Hardly perceptible... | 1 | 88 | 1.47 | .005 |
| Just perceptible ... | 2 | 176 | 2.93 | .020 |
| | 3 | 264 | 4.40 | .044 |
| Gentle breeze ..... | 4 | 352 | 5.87 | .079 |
| | 5 | 440 | 7.33 | .123 |
| Pleasant breeze.... | 10 | 880 | 14.67 | .492 |
| | 15 | 1,320 | 22.00 | 1.107 |
| Brisk gale......... | 20 | 1,760 | 29.33 | 1.968 |
| | 25 | 2,200 | 36.67 | 3.075 |
| High wind........ | 30 | 2,640 | 44.00 | 4.428 |
| | 35 | 3,080 | 51.33 | 6.027 |
| Very high wind.... | 40 | 3,520 | 58.67 | 7.872 |
| | 45 | 3,960 | 66.00 | 9.963 |
| Storm............. | 50 | 4,400 | 73.33 | 12.300 |
| Great storm....... | 60 | 5,280 | 88.00 | 17.712 |
| | 70 | 6,160 | 102.67 | 24.108 |
| Hurricane or cyclone........... | 80 | 7,040 | 117.33 | 31.488 |
| | 100 | 8,800 | 146.67 | 49.200 |

will be the pressure, and the more nearly horizontal the slope, the less will be the pressure. In the following table is given the pressure exerted upon roofs of different slopes, by a wind pressure of 40 lb. per sq. ft. on a vertical plane, which is equivalent in intensity to a violent hurricane.

In addition to wind and snow loads upon roofs, the weight of the principles or roof trusses, including the other features of the construction, should be figured in the estimate. For light roofs having a span of not over 50 ft., and not required

**WIND PRESSURE ON ROOFS, IN POUNDS PER SQUARE FOOT**

| Rise in Inches per Foot of Run | Angle With Horizontal | Pitch, Proportion of Rise to Span | Wind Pressure Normal to Slope |
|---|---|---|---|
| 4 | 18° 26′ | $\frac{1}{6}$ | 16.8 |
| 6 | 26° 34′ | $\frac{1}{4}$ | 23.8 |
| 8 | 33° 41′ | $\frac{1}{3}$ | 29.2 |
| 12 | 45° 0′ | $\frac{1}{2}$ | 36.2 |
| 16 | 53° 8′ | $\frac{2}{3}$ | 38.8 |
| 18 | 56° 19′ | $\frac{3}{4}$ | 39.4 |
| 24 | 63° 26′ | 1 | 40.0 |

to support any ceiling, the weight of the steel construction may be taken at 5 lb. per sq. ft.; for greater spans, 1 lb. per sq. ft. should be added for each 10 ft. increase in the span.

# STRENGTH OF MATERIALS

## DEFINITIONS OF TERMS

**Stress.**—Stress is the cohesive force by which the particles of a body resist the external load that tends to produce an alteration in the form of the body. Stress is always equal to the effective external force acting upon the body; thus, if a bar is subjected to a direct pulling force of 1,000 lb. a stress of 1,000 lb. is induced in the bar. *Unit stress* is the stress per square inch of section. For instance, if the bar just mentioned is 1 in.×2 in. in section, the unit stress of the bar will be 1,000÷2 (sectional area in square inches) = 500 lb.

*Tensile stress* is produced when the external forces tend to stretch a body, or pull the particles away from one another. A rope by which a weight is suspended is an example of a body subjected to tensile stress. *Compressive stress* is produced when the forces tend to compress the body, or push the particles closer together. A post or column of a building is subjected to compressive stress. *Shearing stress* is produced when

the forces tend to cause the particles in one section of a body to slide over those of the adjacent section. A steel plate acted on by the knives of a shear, or a beam carrying a load, is subjected to shearing stress. *Transverse* or *bending stress* is produced by loads acting on a beam tending to bend it, and is a combination of tensile, compressive, and shearing stresses.

The *ultimate strength* of any material is the greatest intensity of stress that the material can stand. The *ultimate elongation* is the total elongation produced in a unit of length of the material of a unit area, by a force equal to the ultimate strength of the material.

**Strain.**—The amount of alteration in form of a body produced by an external force is called *strain*. If a steel wire is subjected to a pulling force, and is elongated $\frac{1}{16}$ in., this alteration is the strain. *Unit strain* is the strain per unit of length. If an iron bar 6 ft. long is subjected to either a tensile or a compressive force that elongates or shortens it 1 in., the unit strain will be $1 \div 72$ (length of bar in inches) = .0139 in.

**Modulus of Elasticity.**—The *modulus* or *coefficient of elasticity* is the ratio between the stresses and corresponding strains for a given material, which modulus of elasticity may have a somewhat different value for tension, compression, and shear.

Let $l$ = strain per unit length of a material subjected to tensile or compressive force;
$p$ = unit stress corresponding to $l$;
$E$ = modulus of elasticity;

then, $$E = \frac{p}{l}$$

For example, a wrought-iron bar, 80 in. long, subjected to a pulling force of 10,000 lb., per unit area, is stretched .029 in. The unit strain $l$, or stretch per inch of length, is $.029 \div 80 = .0003625$ in.

Then, $$E = \frac{10,000}{.0003625} = 27,586,206$$

The relation $E = \frac{p}{l}$ is true only when equal additions of stress correspond to equal increases of strain. Previous to rupture, this condition ceases to exist, and the material is said

to be stressed beyond the elastic limit. The *elastic limit*, therefore, is that degree of stress within which the modulus of elasticity is nearly constant and equal to stress divided by strain.

**Modulus of Rupture.**—The fibers in a beam subjected to transverse loads are either in compression or tension, but the apparent strength of the extreme fibers agrees neither with their compressive nor tensile strength; hence, in beams of

**STRENGTH OF METALS, IN POUNDS PER SQUARE INCH**

| Material | Ultimate Tensile | Ultimate Compression | Ultimate Shearing | Modulus of Rupture | Modulus of Elasticity Millions |
|---|---|---|---|---|---|
| Wrought iron...... | 48,000 | 46,000 | 40,000 | 44,000 | 27 |
| Structural steel (soft)........... | 56,000 | 56,000 | 48,000 | 54,000 | 29 |
| Structural steel (medium)....... | 64,000 | 64,000 | 50,000 | 60,000 | 29 |
| Steel, castings ..... | 70,000 | 70,000 | 60,000 | 70,000 | 30 |
| Cast iron.......... | 15,000 | 80,000 | 18,000 | 30,000 | 12 |
| Brass, cast........ | 24,000 | *30,000 | 36,000 | 20,000 | 9 |
| Bronze, phosphor.. | 50,000 | | | | 14 |
| Bronze, aluminum . | 75,000 | 120,000 | | | |
| Aluminum, commercial......... | 15,000 | 12,000 | 12,000 | | 11 |

uniform cross-section above and below the neutral axis, a constant determined by actual tests is used. This is called the *modulus of rupture*, and is generally expressed in pounds per square inch.

**Factor of Safety**.—The ratio of the breaking strength of the material to the load imposed upon it, under usual conditions is termed the *factor of safety*. For instance, if the ultimate strength of an iron tension bar is 50,000 lb., and the load it sustains is 10,000 lb., the factor of safety is $50{,}000 \div 10{,}000 = 5$.

*Unit stress producing 10% reduction in original length.

## AVERAGE ULTIMATE BREAKING UNIT STRESSES OF TIMBER IN POUNDS PER SQUARE INCH

| Kind of Timber | Tension | | Compression | | | Transverse | | Shearing | |
|---|---|---|---|---|---|---|---|---|---|
| | With Grain | Across Grain | With Grain: End Bearing | With Grain: Columns Under 15 Diams. | Across Grain | Modulus of Rupture or Extreme Fiber Stress | Modulus of Elasticity | With Grain | Across Grain |
| White oak | 12,000 | 2,000 | 7,000 | 5,000 | 2,000 | 7,000 | 1,500,000 | 800 | 4,000 |
| White pine | 7,000 | 500 | 5,500 | 3,500 | 700 | 4,000 | 1,000,000 | 400 | 2,000 |
| Southern long-leaf or Georgia yellow pine | 12,000 | 600 | 7,000 | 5,000 | 1,400 | 7,000 | 1,500,000 | 600 | 5,000 |
| Douglas fir | 8,000 | | 5,700 | 4,500 | 800 | 5,000 | 1,400,000 | 500 | |
| Short-leaf yellow pine | 9,000 | 500 | 6,000 | 4,500 | 1,000 | 6,000 | 1,200,000 | 400 | 4,000 |
| Red pine (Norway pine) | 8,000 | 500 | 5,000 | 4,000 | 800 | 5,000 | 1,130,000 | | |
| Spruce and eastern fir | 8,000 | 500 | 6,000 | 4,000 | 700 | 4,000 | 1,200,000 | 400 | 3,000 |
| Hemlock | 6,000 | | | 4,000 | 600 | 3,500 | 900,000 | 350 | 2,500 |
| Cypress | 6,000 | | 5,000 | 4,000 | 700 | 5,000 | 900,000 | | |
| Cedar | 7,000 | | 5,500 | 3,500 | 700 | 4,000 | 700,000 | 400 | 1,500 |
| Chestnut | 8,500 | | | 4,000 | 900 | 5,000 | 1,000,000 | 600 | 2,000 |
| California redwood | 7,000 | | | 4,000 | 600 | 4,500 | 700,000 | 400 | |
| California spruce | | | | 4,000 | | 5,000 | 1,200,000 | | |
| Factor of safety | 10 | 10 | 5 | 5 | 4 | 6 | 2 | 4 | 4 |

## STRENGTH OF TIMBER AND MASONRY MATERIALS

The table on page 78 gives breaking stresses for timber. The strength of timber depends among other things, on the moisture content of the sticks and the clearness of the stock. These values are for seasoned timber of good grade; for inferior or green stuff, they are too high. At the bottom of the table are factors of safety. This table recommended by the Committee on Strength of Bridge and Trestle Timbers of the Association of Railway Superintendents of Bridges and Building in New Orleans in 1895 has been revised by Mr. George E. Thackray, C. E. and is published in "Cambria Steel", a handbook published by the Cambria Steel Co.

The column headed Compression With Grain shows the ultimate compressive strength parallel to the grain, which values are used in figuring the ultimate strength of columns. The column headed Compression Across Grain gives the allowable compressive strength perpendicular to the grain.

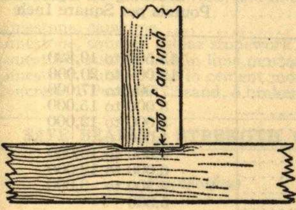



FIG. 1

Fig. 1 shows how this strength is called into play. The column headed Shearing With Grain will be found of use in calculating the resistance of the timber at the heel of a roof truss. For instance; calculate with what force the piece *c* of the tie member *b* in Fig. 2 opposes the thrust of the rafter member *a*. The sectional area of the surface *def* is $10 \times 18 = 180$ sq. in. The ultimate shearing strength of Georgia yellow pine, parallel with the grain, according to the table, is 600 lb.; then, $180 \times 600 = 108{,}000$ lb., the ultimate strength of the timber. If the safe strength is desired, this value is divided by the required factor of safety; if 4 is used the safe strength will be $108{,}000 \div 4 = 27{,}000$ lb. The column, giving the extreme fiber stress or modulus of rupture, for different woods, is used in figuring the strength of beams.

From tests to determine the physical properties of timber, made by the Forestry Division U. S. Dept. of Agriculture, the following conclusions are deduced: That the bleeding of longleaf yellow pine, for sap products, is not detrimental to its durability and strength; also that moisture reduces the strength of timber, whether that moisture is the sap or that absorbed after seasoning.

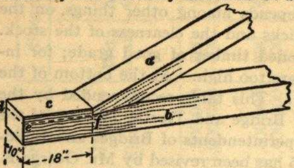


FIG. 2

## ULTIMATE CRUSHING STRENGTH OF MASONRY MATERIALS

| Material | Crushing Strength Pounds per Square Inch |
|---|---|
| Bluestone | 13,500 to 19,820 |
| Granite | 12,000 to 20,000 |
| Limestone | 7,000 to 17,000 |
| Marble | 8,000 to 15,000 |
| Sandstone | 5,000 to 12,000 |
| Brick, light red | 1,000 |
| Brick, good common | 4,000 to 10,000 |
| Brick, best hard | 6,000 to 12,000 |
| Brick, sand-lime | 2,500 to 3,000 |
| Terra cotta | 5,000 |

It should be remembered that the strength of stone varies greatly, and that different specimens of the same stone will show great differences under similar tests. In practice, $\frac{1}{10}$ to $\frac{1}{30}$ of the values in the accompanying table should be used. The results there given bear no definite relation to the strength of masonry in which they are used.

The safe working loads allowable on brickwork and masonry, together with the safe pressures allowable on foundation soils, are given in the following table. These values may be used where there are no local building laws that must be

followed. When a building of importance is to be erected, the nature of the foundation should be carefully ascertained by means of borings and its bearing power obtained by actual tests.

## SAFE BEARING LOADS

| Brick and Stone Masonry | Pounds per Square Inch |
|---|---|
| *Brickwork* | |
| Bricks, hard, laid in lime mortar | 100 |
| Bricks, hard, laid in Portland cement mortar | 200 |
| Bricks, hard, laid in Rosendale cement mortar | 150 |
| *Stonework* | |
| Granite, capstone | 700 |
| Granite, squared ashlar stonework | 350 |
| Sandstone, capstone | 350 |
| Sandstone, squared ashlar stonework | 175 |
| Sandstone, rubble stonework, laid in lime mortar | 80 |
| Sandstone, rubble stonework, laid in cement mortar | 150 |
| Limestone, capstone | 500 |
| Limestone, squared ashlar stonework | 250 |
| Limestone, rubble, laid in lime mortar | 80 |
| Limestone, rubble, laid in cement mortar | 150 |
| Concrete, 1 Portland, 2 sand, 5 broken stone | 300 |

## SAFE BEARING STRENGTH OF FOUNDATIONS

| *Foundations* | Tons per Square Foot |
|---|---|
| Granite formation | 30 |
| Limestone, compact beds | 25 |
| Sandstone, compact beds | 20 |
| Shale formation or soft rock | 8 to 10 |
| Gravel and sand, compact | 6 to 10 |
| Gravel, dry and coarse packed and confined | 6 |
| Gravel and sand, mixed with dry clay | 4 to 6 |
| Clay, absolutely dry and in thick beds | 4 |
| Clay, moderately dry and in thick beds | 3 |
| Clay, soft | $1\frac{1}{2}$ |
| Sand, compact, well-cemented and confined | 4 |
| Sand, clean, dry, in natural beds and confined | 2 |
| Earth, solid, dry, and in natural beds | 4 |

The following table gives the ultimate strength of concrete cubes. The allowable strength of concrete is specified by the various building laws and these change every few years.

**CRUSHING STRENGTH OF CONCRETE CUBES, MADE WITH PORTLAND CEMENT**

| Proportions of Ingredients | | | Crushing Strength, in Pounds per Square Inch | | | |
|---|---|---|---|---|---|---|
| Cement | Sand | Broken Stone | 7 da. | 1 mo. | 3 mo. | 6 mo. |
| 1 | 1 | 3 | 1,600 | 2,750 | 3,360 | 4,300 |
| 1 | 2 | 4 | 1,400 | 2,400 | 2,900 | 3,700 |
| 1 | 2½ | 5 | 1,300 | 2,225 | 2,670 | 3,400 |
| 1 | 3 | 6 | 1,200 | 2,050 | 2,440 | 3,100 |
| 1 | 3½ | 7 | 1,100 | 1,875 | 2,210 | 2,800 |
| 1 | 4 | 8 | 1,000 | 1,700 | 1,980 | 2,500 |
| 1 | 5 | 10 | 800 | 1,350 | 1,520 | 1,900 |
| 1 | 6 | 12 | 600 | 1,000 | 1,060 | 1,300 |

The strength of concrete depends on many factors. The figures given are the result of one set of tests; other tests might give results that would differ from them considerably.

## PROPERTIES OF SECTIONS

### CENTER OF GRAVITY

The *center of gravity* of a figure or body is that point upon which the figure or body will balance in whatever position it may be placed, provided it is acted upon by no other force than gravity.

If a plane figure is alike or symmetrical on both sides of a center line, the latter line is termed an *axis of symmetry*, and the center of gravity lies in this line. If the figure is symmetrical about any other axis, the intersection of the two axes will be the center of gravity of the section. Thus, the center of gravity of a square, rectangle, or other parallelogram is at the intersection of the diagonals; of a circle or ellipse, at the center

of the figure; etc. The center of gravity of a triangle is found at the intersection of lines drawn from the middle of each side to the opposite apex; or, it is two-thirds the distance from any apex to the middle of the opposite side. For any section, the center of gravity may be found by the principles explained under the heading Neutral Axis. It may be determined approximately, but simply, by drawing to scale upon cardboard the outline of the section; then, by cutting out the figure, and balancing it in different directions on a knife edge, the center of gravity will be at the intersection of the lines on which the section balances.

## NEUTRAL AXIS

When a simple beam is loaded, there is always compression in the topmost fibers and tension in the bottommost fibers. There must, therefore, be a certain position in the cross-section at which the fibers are neither in compression nor in tension—that is, they are neutral; hence the position of these neutral fibers is called the *neutral axis* of the section. It can be proved that the neutral axis of the section of a beam made of one material as steel or wood passes through the center of gravity of the section, and at right angles to the direction in which the loads act. If the section of the beam is symmetrical, its axis of symmetry will be a neutral axis, provided it is perpendicular to the line of action of the loads. By finding the center of gravity of a cardboard pattern, the neutral axis of any section may be located.

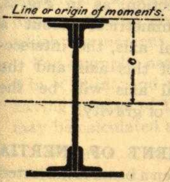



FIG. 1

For simple sections, such as rectangles, triangles, etc., the required neutral axis may be found approximately by the foregoing principles. When, however, the section is made up of combinations of shapes, as in Fig. 1, the distance $c$ of the neutral axis from any line or origin of moments (usually taken at an edge of the section), may be calculated as follows:

**Rule.**—*Find the sum of the products of the area of each elementary section and the perpendicular distance between its center of gravity and the line or origin of moments; divide this sum by*

***the total area of the figure; the result will give the required distance c.***

EXAMPLE.—The distance $c$, in Fig. 2, is thus found; the line or origin of moments being taken at the line $ab$:

| Elementary Section | Dimensions Inches | Area Square Inches | Distance From $ab$ to Center of Gravity Inches | Products Col. 3× Col. 4 |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Upper plate..... | 8"×½" | 4.00 | .25 | 1.00 |
| 2 upper angles .. | *3"×3"×⅝" | 3.36×2 | †1.48 | 9.95 |
| Web-plate...... | 18"×½" | 9.00 | 9.50 | 85.50 |
| 2 lower angles .. | 3½"×3½"×⅝" | 3.99×2 | 17.40 | 138.85 |
| Lower plate..... | 12"×½" | 6.00 | 18.75 | 112.50 |
| Totals........ | | 33.70 | | 347.80 |

Therefore, distance $c$ of neutral axis (and center of gravity) from $ab = 347.80 \div 33.70 = 10.32$ in.

In practice, allowance is made for rivet holes.

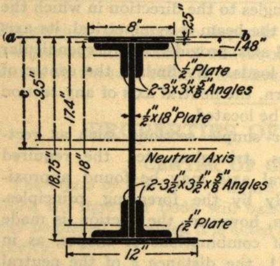



FIG. 2

By finding another neutral axis in similar manner, the intersection of the two axes will be the center of gravity of the section. If the section, as in Fig. 2, is symmetrical about a vertical axis, the intersection of this axis and the neutral axis will be the center of gravity.

## MOMENT OF INERTIA

When a beam is subjected to loading, as in Fig. 3, the fibers of the beam tend to resist the compression at the top and the tension at the bottom, each fiber exerting a force or moment directly proportional

* For areas, see table on page 90. For decimal equivalents of fractions of inches, see page 32. † See table on page 90.

to the distance it is located from the neutral axis (provided the elastic limit of the material is not exceeded); hence, the topmost and bottommost fibers are of considerably more value than those located near the neutral axis. It can therefore be seen that the strength of a beam depends on the

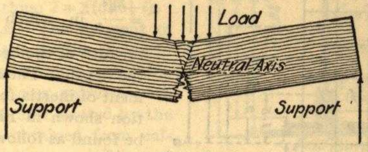



FIG. 3

cross-section of the beam. It depends on a certain property or function of the cross-section called the Moment of Inertia about the neutral axis. The moment of inertia must not be confused with bending moment or any other moment. It is simply the name given arbitrarily to a certain function of the cross-section of beams and columns.

The *moment of inertia* (usually designated by the letter $I$) of any figure or cross-section is the sum of the products of each elementary area of the figure multiplied by the square of its distance from a given line or axis. In beams, the axis about which the moment of inertia is wanted is the neutral axis.

For example, assuming that the section shown in Fig. 4, is 3 in.×12 in., and that it is divided into 36 equal parts, each having an area of 1 sq. in., the approximate moment of inertia may be calculated as follows:

Fibers $b, b, b, b, b, b$ = 6 sq. in.×5.5×5.5 = 181.50
Fibers $c, c, c, c, c, c$ = 6 sq. in.×4.5×4.5 = 121.50
Fibers $d, d, d, d, d, d$ = 6 sq. in.×3.5×3.5 = 73.50
Fibers $e, e, e, e, e, e$ = 6 sq. in.×2.5×2.5 = 37.50
Fibers $f, f, f, f, f, f$ = 6 sq. in.×1.5×1.5 = 13.50
Fibers $g, g, g, g, g, g$ = 6 sq. in.× .5× .5 = 1.50

$I$, or moment of inertia = 429.00

In this manner the approximate moment of inertia for any section may be obtained. The table on page 88, gives convenient formulas by which the moment of inertia for usual sections may be determined. For instance, according to this table, the formula for the moment of inertia of any rectangular section is $I = \frac{bd^3}{12}$, in which $b$ is the breadth of the beam, and $d$ the depth. Thus, the moment of inertia for the section shown in Fig. 4 may be found as follows:

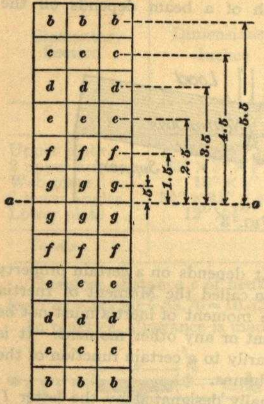


FIG. 4

$$I = \frac{3 \times 12 \times 12 \times 12}{12} = 432,$$

which is nearly the same as the approximate result, 429, obtained in the previous calculation.

On pages 89 and 90 are given tables that contain the moment of inertia of a few **I** beams and angles that are rolled by one or more manufacturers. A great many more sizes are, of course, rolled, also a number of different sections by each company. The tables mentioned are inserted so that the few problems in the text may be solved and represent in no way the complete product of any manufacturer. Manufacturers publish handbooks giving the various properties of all the sections they roll and these handbooks should be used in practical design.

Beam or column sections are often made up of several elementary sections, and the moment of inertia is found thus:

**Rule.**—*The moment of inertia is equal to the sum of the products of each elementary area and the square of its distance from the neutral axis increased by its moment of inertia about a parallel axis through its center of gravity.*

If $i$ represents the moment of inertia of each elementary figure, $a$ the area of each, $d^2$ the square of the perpendicular distance from the center of gravity of each elementary section to the neutral axis $ab$, Fig. 5, and $I$ the required moment of inertia, the rule may be expressed thus: $I = \Sigma(ad^2 + i)$.

EXAMPLE.—The moment of inertia of the section shown in Fig. 2, may be found as follows, the figure being redrawn with the neutral axis located by the distance $c$, obtained from calculations on page 85, and shown in Fig. 5.

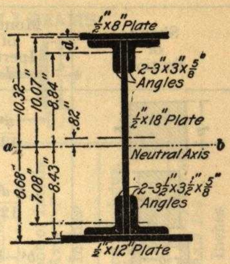



FIG. 5

SOLUTION.—First work out the formula $ad^2+i$ for each elementary section, as in the following table. In practice, allowance is made for rivet holes.

| Elementary Section | Area $a$ Square Inches | $d$ Inches | $d^2$ | $i$ | $ad^2+i$ |
|---|---|---|---|---|---|
| Upper plate... | 4.00 | 10.07 | 101.40 | *.0833 | 405.68 |
| 2 upper angles. | †3.36×2 | 8.84 | 78.15 | †2.62×2 | 530.38 |
| Web plate..... | 9.00 | .82 | .67 | 243. | 249.03 |
| 2 lower angles. | 3.99×2 | 7.08 | 50.13 | 4.33×2 | 408.70 |
| Lower plate... | 6.00 | 8.43 | 71.06 | .125 | 426.49 |

Moment of inertia of section, $I = \Sigma(ad^2+i) = 2020.28$.

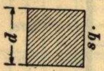
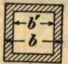
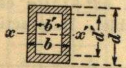
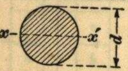
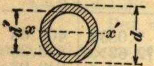
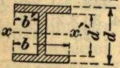
## TABLES OF FORMULAS AND PROPERTIES

The following table gives formulas for ascertaining the moments of inertia, the section moduli, and the squares of the least radius of gyration of a few common sections. The tables of Properties of I Beams and Properties of Angles give useful data regarding these shapes.

---

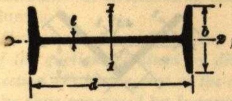
* Figured by formula $\frac{bd^3}{12}$, on page 88. †See page 90.

## FORMULAS FOR MOMENT OF INERTIA, SECTION MODULUS, ETC.

| Shape of Section | Moment of Inertia $I$ | Section Modulus $Q$ | Sq. Least Radius of Gyration $R^2$ |
|---|---|---|---|
|  | $\frac{d^4}{12}$ | $\frac{d^3}{6}$ | $\frac{d^2}{12}$ |
|  | $\frac{b\,d^3}{12}$ | $\frac{b\,d^2}{6}$ | $\frac{b^2}{12}$ |
|  | $\frac{b^4-b'^4}{12}$ | $\frac{I}{.5\,b}$ | $\frac{b^2+b'^2}{12}$ |
|  | $\frac{b\,d^3-b'\,d'^3}{12}$ | $\frac{I}{.5\,d}$ | $\frac{I}{A}$ |
|  | $\frac{\pi\,d^4}{64}$, or $.0491d^4$ | $\frac{\pi\,d^3}{32}$, or $.0982d^3$ | $\frac{d^2}{16}$ |
|  | $.0491(d^4-d'^4)$ | $.0982\left(d^3-\frac{d'^4}{d}\right)$ | $\frac{d^2+d'^2}{16}$ |
|  | $\frac{b\,d^3-2\,b'\,d'^3}{12}$ | $\frac{I}{0.5\,d}$ | $\frac{I}{A}$ |
|  | $\frac{A\,d^2}{6.66}$ (Approx.) | $\frac{A\,d}{3.2}$ (Approx.) | $\frac{I}{A}$ |
|  | $\frac{A\,d^2}{7.34}$ (Approx.) | $\frac{A\,d}{3.67}$ (Approx.) | $\frac{I}{A}$ |

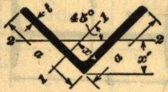
NOTE.—$A$ = total area of section. In calculating the least radius of gyration be sure to use the least moment of inertia. $xx'$ denotes the neutral axis, and the value of $I$ given is that about this axis.

## PROPERTIES OF I BEAMS




| Depth of Beam Inches | Weight per Foot Pounds | Area of Section Square Inches | Thickness of Web Inches | Width of Flange Inches | Moment of Inertia, Axis 1–1 Inches⁴ | Section Modulus, Axis 1–1 Inches³ | Radius of Gyration, Axis 1–1 Inches |
|---|---|---|---|---|---|---|---|
| *d* | | *A* | *t* | *b* | *I* | *Q* | *r* |
| 4 | 7.50 | 2.21 | .19 | 2.66 | 6.0 | 3.0 | 1.64 |
| 4 | 10.50 | 3.09 | .41 | 2.88 | 7.1 | 3.6 | 1.52 |
| 5 | 9.75 | 2.87 | .21 | 3.00 | 12.1 | 4.8 | 2.05 |
| 5 | 14.75 | 4.34 | .50 | 3.29 | 15.1 | 6.1 | 1.87 |
| 6 | 12.25 | 3.61 | .23 | 3.33 | 21.8 | 7.3 | 2.46 |
| 7 | 15.00 | 4.42 | .25 | 3.66 | 36.2 | 10.4 | 2.86 |
| 7 | 20.00 | 5.88 | .46 | 3.87 | 42.2 | 12.1 | 2.68 |
| 8 | 18.00 | 5.33 | .27 | 4.00 | 56.9 | 14.2 | 3.27 |
| 8 | 25.25 | 7.43 | .53 | 4.26 | 68.0 | 17.0 | 3.03 |
| 9 | 21.50 | 6.31 | .29 | 4.33 | 84.9 | 18.9 | 3.67 |
| 9 | 35.00 | 10.29 | .73 | 4.77 | 111.8 | 24.8 | 3.30 |
| 10 | 25.00 | 7.37 | .31 | 4.66 | 122.1 | 24.4 | 4.07 |
| 10 | 40.00 | 11.76 | .75 | 5.10 | 158.7 | 31.7 | 3.67 |
| 12 | 31.50 | 9.26 | .35 | 5.00 | 215.8 | 36.0 | 4.83 |
| 12 | 40.00 | 11.76 | .56 | 5.21 | 245.9 | 41.0 | 4.57 |
| 15 | 42.00 | 12.48 | .41 | 5.50 | 441.8 | 58.9 | 5.95 |
| 15 | 60.00 | 17.66 | .76 | 5.84 | 538.6 | 71.8 | 5.52 |
| 18 | 55.00 | 15.93 | .46 | 6.00 | 795.6 | 88.4 | 7.07 |
| 18 | 70.00 | 20.59 | .72 | 6.26 | 921.2 | 102.4 | 6.69 |
| 20 | 65.00 | 19.08 | .50 | 6.25 | 1,169.5 | 117.0 | 7.83 |
| 20 | 75.00 | 22.06 | .65 | 6.40 | 1,268.8 | 126.9 | 7.58 |

## PROPERTIES OF ANGLES HAVING EQUAL LEGS



| Dimensions Inches | Thickness Inches | Weight per Foot Pounds | Area of Section Square Inches | Distance of Center of Gravity From Back of Leg. Inches | Moment of Inertia, Axis *1–1* Inches$^4$ | Distance of Center of Gravity From External Apex. Inches | Least Moment of Inertia, Axis *2–2* Inches$^4$ |
|---|---|---|---|---|---|---|---|
| $a \times a$ | $t$ | | $A$ | $x$ | $I$ | $x'$ | $I'$ |
| $1 \times 1$ | $\frac{1}{8}$ | .8 | .24 | .30 | .022 | .42 | .009 |
| $1\frac{1}{4} \times 1\frac{1}{4}$ | $\frac{1}{4}$ | 2.0 | .57 | .40 | .077 | .57 | .033 |
| $1\frac{1}{2} \times 1\frac{1}{2}$ | $\frac{1}{4}$ | 2.4 | .69 | .47 | .14 | .66 | .058 |
| $1\frac{3}{4} \times 1\frac{3}{4}$ | $\frac{1}{4}$ | 2.8 | .82 | .53 | .23 | .75 | .094 |
| $2 \times 2$ | $\frac{3}{8}$ | 4.7 | 1.36 | .64 | .48 | .90 | .20 |
| $2\frac{1}{2} \times 2\frac{1}{2}$ | $\frac{1}{4}$ | 4.1 | 1.19 | .72 | .70 | 1.01 | .29 |
| $2\frac{1}{2} \times 2\frac{1}{2}$ | $\frac{1}{2}$ | 7.7 | 2.25 | .81 | 1.23 | 1.14 | .52 |
| $3 \times 3$ | $\frac{3}{8}$ | 7.2 | 2.11 | .89 | 1.76 | 1.26 | .72 |
| $3 \times 3$ | $\frac{5}{8}$ | 11.5 | 3.36 | .98 | 2.62 | 1.38 | 1.12 |
| $3\frac{1}{2} \times 3\frac{1}{2}$ | $\frac{3}{8}$ | 8.5 | 2.49 | 1.01 | 2.87 | 1.43 | 1.16 |
| $3\frac{1}{2} \times 3\frac{1}{2}$ | $\frac{5}{8}$ | 13.6 | 3.99 | 1.10 | 4.33 | 1.56 | 1.82 |
| $3\frac{1}{2} \times 3\frac{1}{2}$ | $\frac{7}{8}$ | 18.3 | 5.36 | 1.19 | 5.53 | 1.68 | 2.43 |
| $4 \times 4$ | $\frac{5}{16}$ | 8.2 | 2.41 | 1.12 | 3.71 | 1.58 | 1.50 |
| $4 \times 4$ | $\frac{3}{8}$ | 9.8 | 2.86 | 1.14 | 4.36 | 1.61 | 1.77 |
| $4 \times 4$ | $\frac{1}{2}$ | 12.8 | 3.75 | 1.18 | 5.56 | 1.67 | 2.28 |
| $4 \times 4$ | $\frac{5}{8}$ | 15.7 | 4.62 | 1.23 | 6.66 | 1.74 | 2.76 |
| $4 \times 4$ | $\frac{7}{8}$ | 21.2 | 6.24 | 1.31 | 8.59 | 1.86 | 3.69 |
| $6 \times 6$ | $\frac{3}{8}$ | 14.9 | 4.36 | 1.64 | 15.39 | 2.32 | 6.19 |
| $6 \times 6$ | $\frac{5}{8}$ | 24.2 | 7.11 | 1.73 | 24.16 | 2.45 | 9.81 |
| $6 \times 6$ | $\frac{7}{8}$ | 33.1 | 9.74 | 1.82 | 31.92 | 2.57 | 13.17 |
| $6 \times 6$ | 1 | 37.4 | 11.00 | 1.86 | 35.46 | 2.64 | 14.78 |
| $8 \times 8$ | $\frac{1}{2}$ | 26.4 | 7.75 | 2.19 | 48.65 | 3.09 | 19.56 |

## RADIUS OF GYRATION

*The radius of gyration*, like moment of inertia, is the expression of a certain value of any section, and is one of the factors in the principal formulas for determining the strength of cast-iron and steel columns.

**Rule.**—*The radius of gyration (R) of any section is equal to the square root of the quotient obtained by dividing the moment of inertia of the section (I) by the area of the section (A).*

The rule may be thus expressed by formula.

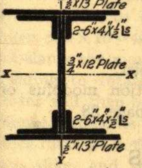


FIG. 1

$$R=\sqrt{\frac{I}{A}};\ or,\ R^2=\frac{I}{A}.$$

Convenient formulas for obtaining the radius of gyration of sections, are given in the table on page 89.

EXAMPLE.—What is the least radius of gyration of the structural steel-column section shown in Fig. 1?

SOLUTION.—The value of $I$, or moment of inertia, on the axis $XX$, is equal to 1,106.06, and on the axis $YY$ it is equal to 359.48. The sectional area is 41 sq. in. Using the least value of $I$, there results,

$$R=\sqrt{\frac{359.48}{41}}=2.97$$

In practice allowance is made for rivet holes.

## SECTION MODULUS

The *section modulus* of a section is equal to the moment of inertia divided by the greatest distance of the neutral axis from the outside fibers of the figure or section. This rule may be expressed in a formula, thus,

$$Q=\frac{I}{c},$$

in which, $Q$ = section modulus;
$I$ = moment of inertia of section;
$c$ = greatest distance from outside fiber to neutral axis.

EXAMPLE.—What is the section modulus for the cross-section of a 3″×12″ joist?

SOLUTION.—As the cross-section is rectangular, the neutral axis must pass through the center of the section, and the distance $c$ is in this case equal to one-half the depth, that is, 6 in. The moment of inertia may be found by the formula $I=\frac{bd^3}{12}$, as given in the table on page 88.

Then, $I=\frac{3\times 12\times 12\times 12}{12}$, or 432.

The values of $c$ and $I$ may then be substituted in the formula for obtaining the section modulus, and

$$Q=\frac{I}{c}=\frac{432}{6}=72$$

which is the section modulus for a 3″×12″ joist.

Formulas for obtaining directly the section modulus of the usual sections are given in the table on page 88.

## BEAMS AND GIRDERS

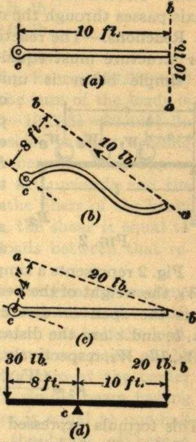
### DEFINITIONS

A body resting upon supports and liable to transverse stress is called a *beam*. Beams are designated by the number and location of the supports, and may be simple, cantilever, fixed, or continuous. A *simple beam* is one that is supported at each end, the distance between its supports being the *span*. A *cantilever* is a beam that has one or both ends overhanging the support; also a beam having one end firmly fixed and the other end free is a cantilever. A *fixed beam* is one that has both ends firmly secured. A *continuous beam* is one that rests upon more than two supports.

### MOMENTS

The *moment* of a force around a fixed point is equal to the force multiplied by its lever arm, which is the perpendicular distance from the line of action of the force to the point; this product is called *foot-pounds* or *inch-pounds*, according to the unit used. Thus in (*a*), in the accompanying illustration, the moment about $c=10\times 10=100$ ft.-lb. In (*b*), the moment about $c$ is $10\times 8=80$ ft.-lb. Likewise in (*c*), the moment around $c$ is $20\times 24=480$ in.-lb. In (*d*), the beam is supported

at $c$; the force $a$ has a moment about $c$ of $30\times8=240$ ft.-lb., acting in a direction contrary to the motion of clock hands. The force $b$ has a moment about $c$ of $20\times10=200$ ft.-lb., acting in the direction of motion of clock hands. It is evident that the beam will turn around $c$ in the direction of the greater moment, with a moment of 240 ft.-lb. − 200 ft.-lb. = 40 ft.-lb.; the beam is, therefore, not in *equilibrium*. If a force of 4 lb. is added to $b$, creating a moment of $4\times10=40$ ft.-lb., to counterbalance the moment of 40 ft.-lb. tending to rotate the beam, the latter will then be in equilibrium. Hence, moments tending to produce rotation in the same direction are alike, and should be added; those acting in opposite directions are unlike, and the smaller should be deducted from the greater. The total moment of a system of forces about a point is the algebraic sum of the moments of all the forces around that point. *If a body is in equilibrium, the algebraic sum of the moments of the forces acting upon that body is zero about any point in that body.*




## THEORY OF BEAMS

If a beam is loaded as at $W$, Fig. 1, the weights produce reactions at the supports. These forces, or reactions, $R_1$, and $R_2$, oppose the action of the weights and their combined action must equal the total weight. The weights and reactions, constituting the e x t e r n a l forces, tend to produce bending in the beam, and are resisted by the internal forces, consisting of the strength of the fibers composing the beam. In a simple beam, the effect of loading is to shorten the

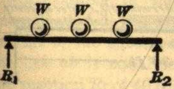



FIG. 1

upper fibers, and to lengthen the lower ones. Somewhere between the top and bottom of the cross-section are located fibers that are neither shortened nor lengthened; this position is the *neutral axis*. In steel and material of homogeneous nature, the neutral axis passes through the center of gravity of the section.

**Reactions.**—The reactions or supporting forces of any beam or structure must equal the loads upon it. If the load upon a simple beam is uniformly distributed, applied at the center of the span, or symmetrically placed and of equal amount upon each side of the center, each reaction $R_1$ and $R_2$ will be equal to one-half the load. When the loads are not symmetrically placed, the reactions are found by the principle of moments as follows:

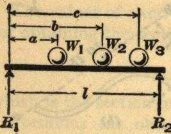



FIG. 2

Fig. 2 represents a simple beam supporting loads $W_1$, $W_2$, and $W_3$, the weight of the beam itself for simplicity being neglected, $l$ is the span or distance between the reactions $R_1$ and $R_2$; $a$, $b$, and $c$ are the distances from the reaction $R_1$ to the loads $W_1$, $W_2$, $W_3$, respectively. Then the right-hand reaction,

$$R_2 = \frac{(W_1 \times a) + (W_2 \times b) + (W_3 \times c.)}{l}$$

This formula expressed in a general rule is:

**Rule.**—*To find the reaction at either support, multiply each load by its distance from the other support, and divide the sum of these products by the distance between supports.*

As the sum of the reactions must equal the sum of the loads, if one reaction is found, the other can be obtained by subtracting the known one from the sum of the loads.

EXAMPLE.—What are the reactions at $R_1$ and $R_2$, Fig. 3?

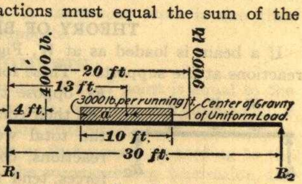



FIG. 3

SOLUTION.—The lever arm of a uniformly distributed load is always the distance from the center of moments to the center of gravity of the load.

The total uniform load $a$ is $3{,}000 \times 10 = 30{,}000$ lb., and the distance of its center of gravity from $R_1$ is 13 ft. The moments of the loads about $R_1$ are as follows:

$$
\begin{aligned}
4{,}000 \times 4 &= 16{,}000 \text{ ft.-lb.}\\
30{,}000 \times 13 &= 390{,}000 \text{ ft.-lb.}\\
9{,}000 \times 20 &= \underline{180{,}000} \text{ ft.-lb.}\\
\text{Total} &= 586{,}000 \text{ ft.-lb.}
\end{aligned}
$$

The distance from $R_1$ to $R_2$ is 30 ft.; hence, $586{,}000 \div 30 = 19{,}533\frac{1}{3}$ lb., the reaction at $R_2$. As the sum of the loads is 43,000 lb., the reaction at $R_1$ is $43{,}000 - 19{,}533\frac{1}{3} = 23{,}466\frac{2}{3}$ lb.

**Shear.**—The loads and reactions, besides causing bending or flexure, create shearing stresses in the beam by their opposing tendency; that is, as the reactions act upwards and the loads downwards, the effect is to shear the fibers of the beam vertically. At any section of a beam, the shear is equal to either reaction minus the sum of the loads between that reaction and the section considered.

The maximum shear is always equal to the greatest reaction. For a simple beam with a uniformly distributed load, the maximum shear is at the supports, and is equal to one-half the load, or to the reaction. The shear changes at every point of the loaded length, the minimum shear being zero at the center of the span. The maximum shear in a simple beam having a single load concentrated at the center is equal to one-half the load, and is uniform throughout the beam. Where a beam supports several concentrated loads, changes in the amount of shear occur only at the points where the loads are applied.

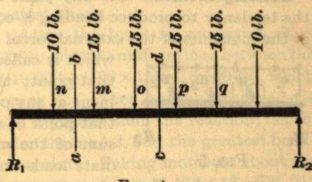



FIG. 4

For example, in the beam loaded as shown in Fig. 4, the shear on the line $ab$ is equal to the reaction $R_1$ of 40 lb. minus the load $n$ of 10 lb., or 30 lb. The shear between $o$ and $p$, on the line $cd$, is equal to the reaction $R_1$ of 40 lb. minus the sum of the loads $n$, $m$, and $o$, or zero. Working from the same

reaction $R_1$, the shear on the beam between $p$ and $q$ is equal to $R_1-(n+m+o+p)$, or 40 lb. − 55 lb. = −15 lb. Thus, all the beam to the left of $o$ is in what may be called *positive shear*, while to the right of $p$ the shear is in the opposite direction, and may be called *negative shear*. It is evident that there is a section in the beam—for instance, $cd$—where the shear changes from positive (+) to negative (−); that is, it passes through zero, or changes sign.

EXAMPLE.—(*a*) What is the maximum shear on the beam shown in Fig. 3? (*b*) What is the shear 11 ft. from the right support? (*c*) Where does the shear change sign?

SOLUTION.—(*a*) As found in the previous example, $R_1 = 23{,}466\frac{2}{3}$ lb. and $R_2 = 19{,}533\frac{1}{3}$ lb. the maximum shear is at $R_1$ and is $23{,}466\frac{2}{3}$ lb.

(*b*) The reaction $R_2$ being $19{,}533\frac{1}{3}$ lb., and there being but a load of 9,000 lb. between it and a section 11 ft. distant, the shear at the latter point is $19{,}533\frac{1}{3}-9{,}000=10{,}533\frac{1}{3}$ lb.

(*c*) Working from $R_1$, the first load is 4,000 lb., and the shear at this point is $23{,}466\frac{2}{3}-4{,}000=19{,}466\frac{2}{3}$ lb. It is clear that the shear becomes negative somewhere in the uniform load, as the latter is 30,000 lb., which is more than $19{,}466\frac{2}{3}$ lb. Dividing $19{,}466\frac{2}{3}$ by 3,000 the load per foot, the result is 6.49 ft., the distance from left end of uniform load to point where the shear changes sign; hence the distance from $R_1$ is $4+4+6.49=14.49$ ft.

**Bending Moment.**—At any point in the length of a beam, the tendency to produce bending is equal to the algebraic sum of the moments of the external forces at one side of that point, which is called the *bending moment* at that point; that is, the bending moment at any point is the moment about that point of either reaction minus the sum of the moments of the intermediate loads about the same point. For example, the bending moments at several points on the beam shown in Fig 5 are as follows: At $W_1 = R_1a$; at $W_2 = R_1(a+b) - W_1b$; at $W_3 = R_1(a+b+c) - (W_2c + W_1(b+c))$, or $R_2d$, etc.

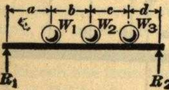


FIG. 5

The bending moment varies, depending on the shear, and attains a maximum value at the point where the shear changes

sign. If the loads are concentrated at several points, the maximum bending moment will be under the load at which the sum of all the loads between one support up to and including the load in question first becomes equal to, or greater than, the reaction at the support. Hence, to find the maximum bending moment in any simple beam:

**Rule**—*Compute the reactions and determine the point where the shear changes sign. Calculate the moment about this point of either reaction, and of each load between the reaction and the point, and subtract the sum of the latter moments from the former.*

Example.—What is the maximum bending moment in inch-pounds of the beam loaded as shown in Fig. 6?

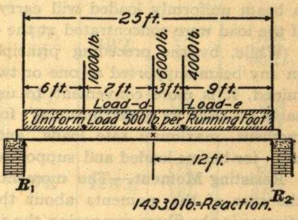



Fig. 6

Solution. — Taking moments about $R_1$ and remembering that a uniform load has the same moment as an equal load concentrated at the center of gravity of the uniform load, the total moment is found to be 358,250 ft.-lb. The span being 25 ft., the reaction $R_2$ is $358{,}250 \div 25 = 14{,}330$ lb. As the sum of the loads is 32,500 lb., the reaction $R_1$ is $32{,}500 - 14{,}330 = 18{,}170$ lb. This is the greatest reaction and greatest shear.

Beginning at $R_1$ and adding the loads in succession, it is found that the load of 10,000 lb. plus the uniform load between the reaction and the load $d$ is $10{,}000 + (500 \times 13) = 16{,}500$ lb., which is less than the left reaction, or $R_1$. When, however, the load $d$ is added, the sum of the loads is greater than the reaction; hence, the shear changes sign under the load $d$, and the greatest bending moment is also at that point. Taking moments about the point under the load $d$, the moment of $R_1$ is $18{,}170 \times 13 = 236{,}210$ ft.-lb. The moments of the loads between $d$ and $R_1$ are:

$$6{,}500 \times 6\tfrac{1}{2} = 42{,}250 \text{ ft.-lb.}$$
$$10{,}000 \times 7 = \underline{70{,}000} \text{ ft.-lb.}$$
$$\text{Total} = 112{,}250 \text{ ft.-lb.}$$

Then, 236,210 ft.-lb. − 112,250 ft.-lb. = 123,960 ft.-lb., the maximum bending moment. The bending moment in inch-pounds is 123,960 ft.-lb. × 12 = 1,487,520 in.-lb.

If $W$ = load and $L$ = span, the maximum bending moment in a simple beam uniformly loaded is $\frac{W}{2}\times\frac{L}{2}-\frac{W}{2}\times\frac{L}{4}=\frac{WL}{8}$. ($\frac{L}{4}$ is distance from center of beam to center of gravity of each half of uniform load.) The maximum bending moment in a beam with a load concentrated at the center is $\frac{WL}{4}$. Thus, a beam uniformly loaded will carry safely twice as much as if the load were concentrated at the center.

While, by the preceding principles, the bending moment in any beam supported at one or two supports may be determined, it is more convenient to use concise formulas. The table on page 99 gives formulas for the maximum bending moment, maximum safe loads, and greatest deflections (or sag), for beams loaded and supported in different ways.

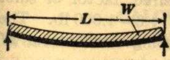
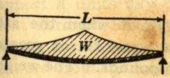
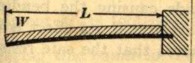
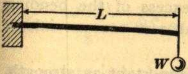
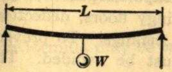
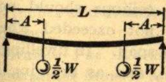
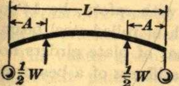
**Resisting Moment.**—The moment of resistance of a beam is the sum of the moments about the neutral axis of all the stresses in the fibers composing the section. The safe resisting moment of any beam section is equal to the product of the safe fiber stress and the moment of inertia divided by the distance from the neutral axis to the extreme fibers.

Let $I$ = moment of inertia;
$c$ = distance, in inches, from neutral axis to extreme fibers;
$S$ = safe fiber stress in pounds per square inch;
$M_1$ = resisting moment;

then $$M_1=\frac{IS}{c}$$

But since $\frac{I}{c}=Q$, the section modulus, $M_1=QS$; that is, the safe resisting moment is equal to the safe fiber stress multiplied by the section modulus. To obtain the safe unit fiber stress, the modulus of rupture of the material is divided by the required factor of safety.

## BEAM FORMULAS

| Method of Loading | | Maximum Bending Moment $M$ | | Maximum Load $W$ | Deflection $D$ |
|---|---|---|---|---|---|
| Length Feet | Load Pounds | Foot-Pound | Inch-Pound | Pound | Inch |
|  | | $\frac{WL}{8}$ | $\frac{3WL}{2}$ | $\frac{2QS}{3L}$ | $\frac{5Wl^3}{384EI}$ |
|  | | $\frac{WL}{6}$ | $2WL$ | $\frac{QS}{2L}$ | $\frac{Wl^3}{60EI}$ |
|  | | $\frac{WL}{2}$ | $6WL$ | $\frac{QS}{6L}$ | $\frac{Wl^3}{8EI}$ |
|  | | $WL$ | $12WL$ | $\frac{QS}{12L}$ | $\frac{Wl^3}{3EI}$ |
|  | | $\frac{WL}{4}$ | $3WL$ | $\frac{QS}{3L}$ | $\frac{Wl^3}{48EI}$ |
|  | | $\frac{WA}{2}$ | $6WA$ | $\frac{QS}{6A}$ | $\frac{Wa}{48EI}\times(3l^2-4a^2)$ |
|  | | $\frac{WA}{2}$ | $6WA$ | $\frac{QS}{6A}$ | Between Supports $\frac{Wa}{16EI}\times(l-2a)^2$ |

NOTE.—$L$ = length, in feet; $l$ = length, in inches; $W$ = total load, in pounds; $E$ = modulus of elasticity; $I$ = moment of inertia; $Q$ = section modulus; $S$ = safe stress on extreme fibers of beam section (= modulus of rupture ÷ factor of safety). In figuring deflections, all lengths must be expressed in inches; and small letters $l$ and $a$ are used as reminders.

EXAMPLE.—What is the safe resisting moment of a short-leaf yellow-pine beam 10 in.×12 in., using a factor of safety of 6 ?

SOLUTION.—In the formula $M_1 = QS$, the section modulus $Q$ for a rectangular section is $\frac{b\,d^2}{6}$ or, for the given section, $Q = \frac{10 \times 12 \times 12}{6} = 240$. As the modulus of rupture for short-leaf yellow pine is 6,000 lb.; the desired factor of safety being 6, the safe unit fiber stress $S$ is $6{,}000 \div 6 = 1{,}000$ lb. Then $QS = 1{,}000 \times 240 = 240{,}000$, the safe resisting moment, or $M_1$, of the beam section in inch-pounds.

A beam will safely support a given load when the safe resisting moment $M_1$, in inch-pounds, is equal to, or greater than, the bending moment $M$ also in inch-pounds. The weight of the beam itself is one of the loads causing the bending moment $M$ and must be taken into account if its effect is of importance. Economical design requires that the safe resisting moment be but little, if any, in excess of the bending moment, having regard, also, to the nearest commercial, or stock, sizes.

**Deflection.**—Stiffness in beams is as important as strength. Lack of stiffness causes vibrations, springy floors, deflection, or sagging, producing plaster cracks in ceilings. To prevent excessive deflection, shallow beams must be avoided. The deflection of beams carrying plastered ceilings should not exceed $\frac{1}{360}$ span. Usually this limit is not exceeded when the depth of wooden beams is at least $\frac{1}{16}$ span. In dwellings, the full floor load being seldom realized, and as bridging is used between joists, their depth may, with safety, be 14 in. for a span as great as 22 ft. The depth of rolled-steel beams should not be less than $\frac{1}{24}$ span, and that of plate girders not less than $\frac{1}{15}$. If doubt exists as to the stiffness of a beam, its deflection should be calculated, and if found excessive, the load should be diminished, or the size of beam increased.

EXAMPLE.—A 6″×10″ long-leaf yellow pine beam, uniformly loaded with 5,000 lb., has a span of 16 ft. 8 in. What is the deflection?

SOLUTION.—From the table of beam formulas, the deflection $= \frac{5\,Wl^3}{384\,EI}$; $E = 1{,}500{,}000$; $I = \frac{bd^3}{12} = \frac{6 \times 1{,}000}{12} = 500$. Hence, deflection $= \frac{5 \times 5{,}000 \times 8{,}000{,}000}{384 \times 1{,}500{,}000 \times 500} = .7$ in. (about).

NOTE.—On account of the peculiarity of *wooden* beams to increase their deflection under constant loads, many engineers divide the usual value of $E$, given for wood by 2 when calculating deflection.

## CALCULATION OF BEAMS

**Wooden Beams.**—Wooden beams are principally used to support a uniformly distributed load, consequently a convenient formula for determining directly the safe strength of rectangular beams uniformly loaded is useful, and may be deduced from the foregoing principles as follows: The bending moment $M$, in foot-pounds, is $\frac{WL}{8}$; or in inch-pounds, $\frac{12\,WL}{8}$. Placing this equal to the resisting moment, $M_1$, or $QS$, there results $\frac{12\,WL}{8} = QS$, or $12\,WL = 8\,QS$; whence $W = \frac{8\,QS}{12\,L} = \frac{2\,QS}{3\,L}$. For a rectangular beam, the section modulus $Q = \frac{bd^2}{6}$, therefore this formula may be written $W = \frac{2\,S}{3\,L} \times \frac{bd^2}{6} = \frac{Sbd^2}{9\,L}$; $b$ and $d$ are in inches and $L$ in feet. This formula expressed in words is as follows:

**Rule.**—*The safe uniformly distributed load, in pounds, for a rectangular beam is equal to the safe unit fiber stress multiplied by the breadth, in inches, and by the square of the depth in inches, and the product divided by 9 times the span, in feet.*

The values given in the following table are safe loads for short-leaf pine beams, with a factor of safety of 6. For hemlock multiply tabular values by $\frac{6}{10}$, and for Georgia yellow pine, multiply tabular values by $1\frac{1}{5}$.

This table is calculated for a maximum fiber stress of 1,000 lb. per sq. in., but may be used with any fiber stress by dividing that stress by 1,000 and multiplying by the tabular value; thus,

for a stress of 800 lb., the safe load is .8 multiplied by the tabular value. Loads given below the heavy zigzag line produce deflections likely to crack plastered ceilings.

## SAFE UNIFORMLY DISTRIBUTED LOADS FOR RECTANGULAR WOODEN BEAMS, 1 IN. THICK

| Span Feet | Depth of Beam | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 6 In. | 7 In. | 8 In. | 9 In. | 10 In. | 12 In. | 14 In. | 16 In. |
| 5 | 800 | 1,090 | 1,420 | 1,800 | 2,220 | 3,200 | 4,355 | 5,690 |
| 6 | 665 | 905 | 1,185 | 1,500 | 1,850 | 2,665 | 3,630 | 4,740 |
| 7 | 570 | 780 | 1,015 | 1,285 | 1,585 | 2,285 | 3,110 | 4,065 |
| 8 | 500 | 680 | 890 | 1,125 | 1,390 | 2,000 | 2,720 | 3,555 |
| 9 | 445 | 605 | 790 | 1,000 | 1,235 | 1,780 | 2,420 | 3,160 |
| 10 | 400 | 545 | 710 | 900 | 1,110 | 1,600 | 2,180 | 2,845 |
| 11 | 365 | 495 | 645 | 820 | 1,010 | 1,455 | 1,980 | 2,585 |
| 12 | 335 | 455 | 595 | 750 | 925 | 1,335 | 1,815 | 2,370 |
| 13 | 310 | 420 | 545 | 690 | 855 | 1,230 | 1,675 | 2,190 |
| 14 | 285 | 390 | 510 | 645 | 795 | 1,145 | 1,555 | 2,030 |
| 15 | 265 | 365 | 475 | 600 | 740 | 1,065 | 1,450 | 1,895 |
| 16 | 250 | 340 | 445 | 560 | 695 | 1,000 | 1,360 | 1,780 |
| 17 | | 320 | 420 | 530 | 655 | 940 | 1,280 | 1,675 |
| 18 | | 300 | 395 | 500 | 615 | 890 | 1,210 | 1,580 |
| 19 | | | 375 | 475 | 585 | 840 | 1,145 | 1,495 |
| 20 | | | 355 | 450 | 555 | 800 | 1,090 | 1,420 |
| 21 | | | | 430 | 530 | 760 | 1,035 | 1,355 |
| 22 | | | | 410 | 505 | 720 | 990 | 1,295 |
| 23 | | | | | 485 | 695 | 945 | 1,235 |
| 24 | | | | | 465 | 665 | 905 | 1,185 |
| 25 | | | | | | 640 | 870 | 1,140 |
| 26 | | | | | | 615 | 840 | 1,095 |
| 27 | | | | | | | 805 | 1,055 |
| 28 | | | | | | | 780 | 1,015 |
| 29 | | | | | | | | 980 |
| 30 | | | | | | | | 950 |

Safe load for any thickness = safe load for 1 in. × thickness, in inches.

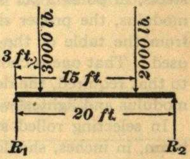
Thickness for any load = load ÷ safe load for 1 in.

EXAMPLE.—What uniformly distributed load will a hemlock joist 3 in. × 14 in. safely support, the span being 20 ft., and the factor of safety 5?

SOLUTION.— In the formula $W = \frac{Sbd^2}{9L}$, $S = 3{,}500$ lb., the modulus of rupture of hemlock, $\div 5$, the factor of safety, $= 700$ lb. per sq. in.; $b = 3$ in.; $d^2 = 14 \times 14 = 196$; and $L = 20$ ft. Then the safe uniformly distributed load $W = \frac{700 \times 3 \times 196}{9 \times 20}$ $= 2{,}287$ lb.

Or, from the table just given, the safe load with a fiber stress of 1,000 lb. per sq, in. for this beam = the load for 1 in. width × the given width, or $1{,}090 \times 3 = 3{,}270$ lb.; but for a safe stress of 700 lb. per sq. in., the safe load is $\frac{700}{1{,}000}$, or .7 of 3,270 lb. = 2,289 lb.

The following example shows how to calculate the size of a rectangular beam necessary to support concentrated loads:




EXAMPLE.—What size Georgia yellow-pine joist is required to support two concentrated loads placed as shown in the accompanying figure, using a factor of safety of 6?

SOLUTION.—The reaction $R_2 = \frac{(3{,}000 \times 3) + (2{,}000 \times 15)}{20}$ $= 1{,}950$ lb., and $R_1 = (3{,}000 + 2{,}000) - 1{,}950 = 3{,}050$ lb. The greatest bending moment $M$ is found, by trial, to be under the 2,000 lb. load, and is equal to $1{,}950 \times 5 = 9{,}750$ ft.-lb., or 117,000 in.-lb. Such a section must be obtained that will have a resisting moment equal to this bending moment of 117,000 in.-lb. The modulus of rupture of yellow pine, 7,000 lb., divided by the factor of safety 6, gives a unit fiber stress of 1,167 lb. Then as the resisting moment of any beam section, $M_1 = QS$, by transposition, $Q = \frac{M_1}{S}$, or $\frac{117{,}000}{1{,}167} = 100$, the required section modulus.

For any rectangular section, $Q = \frac{bd^2}{6}$. By trial, the value of $Q$ for a $3'' \times 12''$ beam is 72; as this is evidently too small,

a 5″×12″ beam is tried. For this, $Q$ is 120, which is sufficient and will probably include also the weight of the beam, which has been neglected so far; this beam is therefore selected, provided it can be obtained as a stock size.

**Rolled-Steel Beams.**—In calculating the size of steel beam sections, the greatest bending moment is first calculated; then the section modulus required is equal to the bending moment in inch-pounds divided by the safe unit fiber stress, obtained by dividing the modulus of rupture of the material by the factor of safety. This may be expressed in formula as $Q=\frac{M}{S}$, in which, as before, $Q$ = section modulus, $M$ = bending moment, in inch-pounds, and $S$ = safe or allowable unit fiber stress, in pounds per square inch. Having found the section modulus, the proper size channel or **I** beam may be selected from the table of the manufacturer whose material is to be used. That one is chosen which has a section modulus nearest to that required, the deepest beam having the required section modulus and lightest weight being preferred.

In selecting rolled structural-steel beams the depth of the beam, in inches, should never be less than one-half the span, in feet, in order to avoid excessive deflection, which causes cracks in plastered ceilings. For instance, if the span is 20 ft., a beam should be not less than 10 in. deep.

Example.—The brick-and-concrete floor of an office building weighs 110 lb. per sq. ft., and is designed for a live load of 40 lb. per sq. ft. The span of the beams is 20 ft., and they are spaced 5 ft. on centers. What size steel **I** beams are required?

Solution.—Total load is $110+40=150$ lb. per sq. ft.; floor surface supported upon one beam is $20\times5=100$ sq. ft.; total load on one beam is $100\times150=15{,}000$ lb. $=W$. The load being uniformly distributed, the bending moment $M$ is $\frac{WL}{8}=\frac{15{,}000\times20}{8}=37{,}500$ ft.-lb., or 450,000 in.-lb.

Suppose that it is decided to use an allowable unit fiber stress in bending of 16,000 lb. per sq. in. the section modulus, $Q=\frac{M}{S}$;

substituting the values of $M$ and $S$, $Q=\frac{450{,}000}{16{,}000}=28.125$. As a 10-in. beam weighing 40 lb. per ft. has a section modulus of 31.7, it will meet the requirements. It is, however, seen that for a 12-in. beam, weighing $31\frac{1}{2}$ lb. per ft., $Q=36$; and on account of its greater strength and less weight, this beam would be the most economical.

**Stone Beams.**—The strength of lintels, flagstones, etc. may be calculated as rectangular beams, except that it is usual to use a factor of safety at least of 10. It is, however, more convenient to use the formula,

$$W=\frac{bd^2}{l}\times c,$$

in which $W$ = safe uniformly distributed load, in tons of 2,000 lb.

$b$ = breadth of beam, in inches;
$d$ = depth of beam, in inches;
$l$ = span of beam, in inches;
$c$ = coefficient taken from following table.

| Kind of Stone | Coefficient |
|---|---|
| Bluestone | .125 |
| Granite | .100 |
| Limestone | .083 |
| Sandstone | .060 |
| Slate | .275 |

EXAMPLE.—A limestone lintel 20 in. wide × 14 in. thick spans a 42-in, opening. What is the safe distributed load?

SOLUTION.—Substituting values in the formula, $\frac{bd^2}{l}\times c$,

$$W=\frac{20\times 14\times 14}{42}\times .083=7.74 \text{ T.}=15{,}480 \text{ lb.}$$

The weight of all beams and especially stone beams must be considered if of importance.

## GIRDERS

In the design of buildings, cases often occur where a single **I** beam will not be sufficient to support a given load. In such

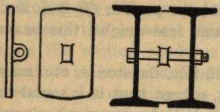


FIG. 1

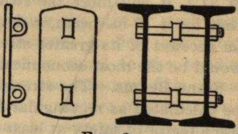


FIG. 2

cases two or more **I** beams are often placed side by side and connected by means of bolts and separators. The *separators* are generally made of cast iron and are fitted between the webs and flanges of the beams as shown in Figs. 1 and 2. In Fig. 1 is shown a separator with one bolt which is used for **I** beams with a depth of 12 in. or less. In Fig. 2 a separator with two bolts is shown; this is used where the **I** beams are more than 12 in. in depth.

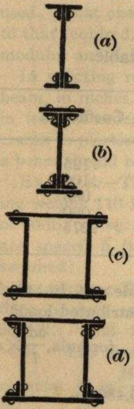


FIG. 3

The Bethlehem Steel Company manufactures girder beams that have a section similar to that of an **I** beam, and from 8 in. to 30 in. in depth, having flanges from 8 in. to 15 in. wide.

There are various forms of built-up girders, called *plate girders, box girders,* etc., which are made by riveting together rolled shapes and plates. These girders are built and used for spans as great as 60 ft. The depth of a plate girder should never be less than one-fifteenth of the span, while some engineers hold that for economy in the construction of the girder, it should have a depth equal to one-twelfth of its span. Handbooks issued by manufacturers of rolled steel give tables showing different types of girders and the loads that they will safely carry. In Fig. 3 are shown some of the more common types of plate

girders and box girders. Sections of two plate and angle girders are shown in (*a*) and (*b*) and sections of two box girders in (*c*) and (*d*).

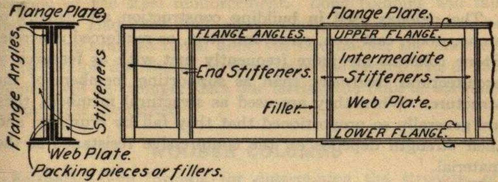



FIG. 4

In very large built-up girders, such as are shown in Fig 4, in which the web-plate is deep, there is danger of the web buckling due to the shearing stresses caused by the load upon it. In such cases, stiffeners, consisting of angles tightly fitted between the flanges are riveted to the web at suitable intervals. Stiffeners are also generally placed at the ends of the girder and at the edge of the supporting wall as shown in Fig. 5; also, under concentrated loads that the girder may support. Cover-plates or flange-plates are sometimes used to strengthen the flanges of the girder at the point of greatest bending moment. The design of complicated girders should be invariably left to persons skilled in the work.

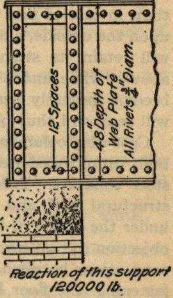



FIG. 5

# COLUMNS

## GENERAL DESCRIPTION

The *columns* used in building construction are usually of stone, wood, cast iron, structural steel, or reinforced concrete. Stone columns are more frequently met with as features of architectural treatment than as supporting members of the structure. When they are used as structural members, they are generally so proportioned that they fail by crushing, and their strength depends on the compressive resistance of the material.

Wooden columns have their principal use in such buildings as large stores, factories, and warehouses, constituting part of a system of slow-burning construction, which many consider to be superior to partially fireproof construction embodying cast-iron columns. The argument advanced is that, in case of fire, the wooden columns will become charred upon the outside, and, thus protected, the body of the column will retain its strength and successfully support the loads above; while under similar conditions cast-iron columns will become intensely heated, and, if water is played upon them, will snap and thus prematurely destroy the building.

Cast-iron columns are rapidly being superseded by those built up of rolled-steel sections, or as they are called, structural-steel columns. This is evidently due to the low price of structural steel, and also to the untrustworthiness of cast iron under the action of fire and suddenly applied loads. Another objection to cast-iron columns is the difficulty of making rigid connections between the columns of the several floors, and of fastening the floor beams to the columns. This objection becomes serious when the height of the building increases to eight or twelve stories; it is on record that, on account of this lack of rigidity in the connections, a certain building in New York was forced by the wind 11 in. out of plumb.

Reinforced-concrete columns with longitudinal, or hooped reinforcement, or with a steel core, are used largely in mill and factory buildings as features of reinforced-concrete systems of construction.

## STRENGTH OF COLUMNS

The *strength of columns* depends on their length and shape of cross-section; and in the case of concrete columns on the disposition of the steel reinforcement. Long columns will fail under less load than will short columns. Of two columns having the same sectional area, the one having the material in the section distributed farthest from the central axis of the column will be stronger than one having the bulk of material located near the center.

## WOODEN COLUMNS

**Formula.**—The formula for determining the strength of wooden columns having flat or square ends was deduced from exhaustive tests of full-size specimens, made at the Watertown Arsenal, Mass., and may be expressed as follows:

$$S = U - \left(\frac{Ul}{100\,d}\right),$$

in which $S$ = ultimate strength of column per square inch of section;
$U$ = ultimate compressive strength of material per square inch;
$l$ = length of column, in inches;
$d$ = dimension of least side of column, in inches.

This formula may be applied to all wooden columns, the length or height of which is not under 10 times nor over 45 times the dimension of the least side. In other words, $\frac{l}{d}$ should not be less than 10 nor more than 45. If the length is less than 10 times the least side, the direct compressive strength of the material per square inch, multiplied by the sectional area of the column, in square inches, will give the strength of the column. If the length is over 45 times the least side, this formula will not apply; in such cases, provision must be made for bracing the column in all directions, or the load upon it must be greatly reduced. Columns of this proportion, however, seldom occur in building practice.

Having determined $S$, the breaking load per square inch of section, the safe load per square inch will be obtained by

dividing by the required factor of safety, 4, 5, or 6. This result, multiplied by the sectional area, will give the safe load the column will sustain.

EXAMPLE.—What safe load will a 10″×12″ short-leaf yellow-pine column 20 ft. long support, provided a factor of safety of 5 is used?

SOLUTION.—In the formula $S=U-\left(\frac{Ul}{100\,d}\right)$, the value of $U$ for short-leaf yellow pine is given in the table on page 78, as 4,000; $l$ is equal to $20\times12=240$ in.; and the least side of the column, or $d$, is 10 in. By substituting these values in the formula, $S=4{,}000-\left(\frac{4{,}000\times240}{100\times10}\right)=3{,}040$ lb., the ultimate or breaking strength of the column per square inch of cross-section.

Then, $3{,}040\div5$ (factor of safety) $=608$ lb., the safe strength of the column to compression per square inch of section.

The sectional area of the column is $12\times10=120$ sq. in.; hence, the safe load that the column will support is equal to $608\times120$, or 72,960 lb.

**Details of Design.**—For slow-burning construction, the Fire Underwriters' Association will not allow the use of square wooden columns less than 8 in. on a side; so, although the actual required size of column to sustain the load safely might be much less than 8 in., it is not advisable in first-class buildings of this construction to use wooden columns less than this in size. Large timber posts, that is posts not under 8 or 10 in. least dimension, are considered as offering more resistance to fire than cast-iron columns; hence, they are often used, especially in mill construction, in preference to the latter.

Care should be taken in selecting timber for columns or posts to obtain only seasoned wood, without wind or twist, free from defects likely to affect its strength. The ends of the posts should be cut square, so as to take a uniform bearing at the base and cap plates. The timber commonly used for posts is yellow pine, which includes the short-leaf and long-leaf, or Georgia pines; white pine, spruce, and Oregon spruce are frequently used, and in some instances, oak. Details of the

## APPROXIMATE BREAKING LOADS FOR HEMLOCK OR SPRUCE COLUMNS

| Length Feet | Size of Column, in Inches | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 6×6 | 7×7 | 8×8 | 9×9 | 10×10 | 11×11 | 12×12 | 13×13 | 14×14 | 16×16 |
| | Breaking Load, in Thousands of Pounds | | | | | | | | | |
| 8 | 121 | 169 | 225 | | | | | | | |
| 9 | 118 | 166 | 221 | 285 | | | | | | |
| 10 | 115 | 162 | 218 | 281 | 352 | | | | | |
| 11 | 112 | 159 | 214 | 276 | 347 | 426 | | | | |
| 12 | 109 | 156 | 210 | 272 | 342 | 421 | 507 | | | |
| 13 | 107 | 152 | 206 | 268 | 338 | 415 | 501 | 595 | | |
| 14 | 104 | 149 | 202 | 263 | 333 | 410 | 495 | 589 | 690 | |
| 15 | 101 | 146 | 198 | 259 | 328 | 405 | 490 | 582 | 683 | 909 |
| 16 | 98 | 142 | 195 | 255 | 323 | 400 | 484 | 576 | 676 | 901 |
| 17 | 95 | 139 | 191 | 251 | 318 | 394 | 478 | 570 | 670 | 893 |
| 18 | 92 | 136 | 187 | 246 | 314 | 389 | 472 | 564 | 663 | 886 |
| 19 | 89 | 132 | 183 | 242 | 309 | 384 | 467 | 557 | 656 | 878 |
| 20 | 86 | 129 | 179 | 238 | 304 | 378 | 461 | 551 | 650 | 870 |

usual cast-iron caps and bases that are used with wooden columns are given on page 251.

**Breaking Loads of Wooden Columns.**—In the table on page 111, are given the approximate breaking loads for hemlock and spruce columns, in thousands of pounds. These values have been calculated by the formula $S = U - \left(\frac{Ul}{100\,d}\right)$; when $U = 4{,}000$ lb. The strengths of red or Norway pine, eastern fir, cypress, chestnut and California redwood are practically the same as in the table. For white pine, take seven-eighths of the above loads. For Georgia yellow pine and white oak multiply by $1\frac{1}{4}$. By dividing the values in all cases by the required factor of safety, usually 5, the safe supporting strength of the column will be obtained.

## CAST-IRON COLUMNS

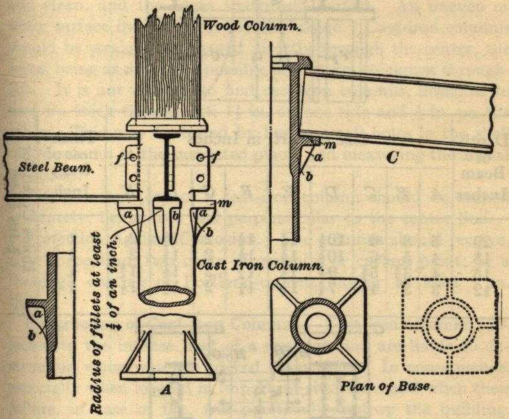
**Design of Cast-Iron Columns.**—In the design for a circular cast-iron column here given, *A* shows the elevation for the cap and brackets supporting steel floor beams. Special care should be exercised in the design of the bracket *a*, the web being made, as shown in *A* to extend to the edge of the plate *m*, and with the general outline of its front edge forming an angle of about 60° with *m*. If the web is made as shown at *a* in *C*, and the beam takes a bearing upon the edge of the plate *m*, the tendency will be to fracture the edge of the bracket. It is well to have at least $\frac{1}{4}$ in. fillets in all the corners of the casting, and also to thicken the metal in the column adjacent to the brackets, as shown at *b*.

The bolt holes *f* should be always drilled, either in the casting or in the steel beams after the latter are in place, because, if the holes are cored in the casting and the holes punched in the beams at the mill, it is likely that the beams will be supported entirely by the shear of the bolts, without bearing upon the bracket at all. The bolts should fit the bolt holes *f* closely, and it is best, if practicable, to drill the holes in both beams and cast-iron flange; this will insure as rigid a connection as is possible with this form of construction.

The strengthening webs of the base should always be placed in the most effective position, that is, on the diagonals, as

shown. If placed on the diameters, the corners will have a tendency to break off, thus reducing the bearing surface of the base.

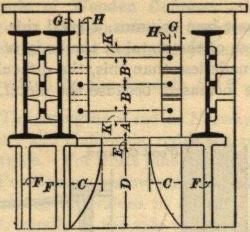
In designing cast-iron columns, a good rule to observe is to have the thickness of the metal in the body of the column not under $\frac{3}{4}$ in. If made less than this, the difficulty of obtaining sound castings is increased, because the metal, in flowing into



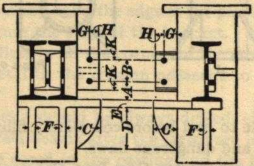

the mold, is liable to cool before completely filling it, and thus form weak spots and dangerous flaws.

**Standard Connections for Cast-Iron Columns.**—Many concerns have their own standard designs of column connections and brackets. The following table gives the standard dimensions of brackets on cast-iron columns for **I** beams, single and double. The shelf or bearing surface of the bracket should be cast with a slope of $\frac{1}{8}$ in. in 1 ft., so that when the beam deflects it will not bear on the edge of the bracket.

## DIMENSIONS OF STANDARD CONNECTIONS FOR CAST-IRON COLUMNS




| Depth of Beam Inches | Size of Part, in Inches | | | | | | | | | Thickness of Lugs Inch | Holes Cored for ¾-In. Bolts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | K | | |
| 20 | 5 | 5 | 6 | 10½ | 1½ | 1½ | 2 | 1½ | 2 | 1 | |
| 18 | 4 | 5 | 6 | 10½ | 1½ | 1½ | 2 | 1½ | 2 | 1 | |
| 15 | 4 | 3½ | 5½ | 9½ | 1½ | 1¼ | 2 | 1½ | 1¾ | 1 | |
| 12 | 3 | 3 | 4½ | 7¾ | 1¼ | 1¼ | 2 | 1½ | 1½ | 1 | |




| Depth of Beam Inches | Size of Part, in Inches | | | | | | | | | Thickness of Lugs Inch | Holes Cored for ¾-in. Bolts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | K | | |
| 10 | 3¼ | 3½ | 4 | 7 | 1¼ | 1 | 2 | 1½ | 1½ | 1 | |
| 9 | 3 | 3 | 4 | 7 | 1 | 1 | 2 | 1½ | 1½ | 1 | |
| 8 | 2½ | 3 | 4 | 7 | 1 | 1 | 2 | 1½ | 1½ | ¾ | |
| 7 | 2¼ | 2½ | 4 | 7 | 1 | 1 | 2 | 1½ | 1½ | ¾ | |

**Inspection of Cast-Iron Columns.**—All building castings, and especially columns, should be carefully inspected before being placed in the building. Air bubbles and blowholes are a common and dangerous source of weakness, and should be searched for by tapping the casting with a hammer. Bubbles or flaws filled in with sand from the mold, or purposely stopped with loam, cause a dullness in the sound. The casting should be free from flaws of any kind, with the exterior surface smooth and clean, and the edges sharp and perfect. An uneven or wavy surface indicates unequal shrinkage. Cast-iron columns should be straight, and cored directly through the center, the metal being as nearly as possible of uniform thickness throughout. It is not unusual to find cast-iron columns, designed to be $\frac{3}{4}$ in. thick throughout, $1\frac{1}{4}$ in. on one side and $\frac{1}{4}$ in. on the other. This may be tested by boring small holes in the shell of the column at the suspected places and measuring the actual thickness.

The base and cap of a cast-iron column should be turned accurately, being true and perpendicular to the center line.

**Protection Against Corrosion.**—The columns should receive, after inspection, two coats of graphite or carbon paint; or a thorough coating of Portland-cement mortar at least $\frac{1}{4}$ in. thick.

**Fireproofing of Cast-Iron Columns.**—Cast-iron columns subjected to the intense heat of a conflagration are liable to destruction when water is played upon them. In consequence, especially when located in important situations and when their failure, in case of fire, will practically destroy the building, they should be thoroughly fireproofed. There are several means employed to accomplish this. The columns may be incased in a light cast-iron shell, an air space of from 1 to 3 in. being left between the column and the casing; this space is sometimes, but not usually, filled with an incombustible, nonconductive material. Two rough and one finish coats of good, hard, mortar plaster laid upon an expanded metal lathing, surrounding the column, with an air space between, make a good fireproof protection. Terra-cotta tile is also much used.

**Breaking Weights of Cast-Iron Columns.**—The accompanying table gives the breaking weights and also the safe loads, in

pounds per square inch, for hollow, round and rectangular cast-iron columns. For the round column, the formula used is

$$P=\frac{10,000}{1+\frac{l^2}{800\,d^2}}$$

For the rectangular columns, the formula used is $P=\frac{80,000}{1+\frac{l^2}{1,067\,d^2}}$

## BREAKING WEIGHTS AND SAFE LOADS OF CAST-IRON COLUMNS

| Length Divided by Least External Breadth or Diameter, in Inches | Breaking Weight, in Pounds per Square Inch | | Safe Loads, in Pounds per Square Inch, Safety Factor 8 | |
|---|---|---|---|---|
| | Round | Rect-angular | Round | Rect-angular |
| 8 | 74,074 | 75,470 | 9,259 | 9,433 |
| 9 | 72,661 | 74,350 | 9,082 | 9,293 |
| 10 | 71,110 | 73,126 | 8,888 | 9,140 |
| 11 | 69,505 | 71,870 | 8,688 | 8,983 |
| 12 | 67,800 | 70,487 | 8,475 | 8,111 |
| 13. | 66,060 | 69,084 | 8,257 | 8,635 |
| 14 | 64,257 | 67,567 | 8,032 | 8,446 |
| 15 | 62,450 | 66,060 | 7,806 | 8,257 |
| 16 | 60,606 | 64,516 | 7,576 | 8,064 |
| 17 | 58,780 | 62,942 | 7,347 | 7,867 |
| 18 | 56,940 | 61,360 | 7,117 | 7,670 |
| 19 | 55,134 | 59,745 | 6,892 | 7,468 |
| 20 | 53,333 | 58,180 | 6,666 | 7,272 |
| 21 | 51,580 | 56,610 | 6,447 | 7,076 |
| 22 | 49,843 | 55,020 | 6,230 | 6,877 |
| 23 | 48,163 | 53,470 | 6,020 | 6,684 |
| 24 | 46,512 | 51,950 | 5,814 | 6,494 |
| 25 | 44,918 | 50,440 | 5,614 | 6,305 |
| 26 | 43,360 | 48,960 | 5,420 | 6,120 |
| 27 | 41,862 | 47,530 | 5,233 | 5,940 |
| 28 | 40,404 | 46,110 | 5,050 | 5,764 |
| 29 | 39,000 | 44,742 | 4,875 | 5,592 |
| 30 | 37,647 | 43,390 | 4,706 | 5,424 |
| 31 | 36,347 | 42,080 | 4,543 | 5,260 |
| 32 | 35,090 | 40,816 | 4,386 | 5,102 |
| 33 | 33,884 | 39,580 | 4,235 | 4,947 |
| 34 | 32,720 | 38,380 | 4,090 | 4,797 |
| 35 | 31,608 | 37,244 | 3,951 | 4,655 |
| 36 | 30,534 | 36,120 | 3,817 | 4,515 |

in which $P$ = safe load, in pounds per square inch of column section;
$l$ = length of column, in inches;
$d$ = outside diameter of column, in inches.

The ultimate compressive strength is taken at 80,000 lb. per sq. in. and a factor of safety of 8 is used.

EXAMPLE.—What load will a rectangular column $8'' \times 12'' \times 1''$ thick and 16 ft. long, bear with safety?

SOLUTION.—The length is $16 \times 12 = 192$ in., which divided by the least breadth of the column, is $192 \div 8 = 24$. Finding in the first column of the table the number 24, in the same line in the last column the safe load of the column is given as 6,494 lb. per sq. in. The area of the cross-section of an $8'' \times 12'' \times 1''$ column is 36 sq. in. The safe load for the column is therefore $36 \times 6{,}494 = 233{,}784$ lb., or 116.9 T.

## STRUCTURAL-STEEL COLUMNS

**Formulas.**—Structural steel concentrically loaded columns with flat ends may be designed by the following formulas. The formulas embody their own factor of safety and give safe values, not ultimate values.

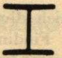
$$S_f \text{ (for medium steel)} = \begin{cases} 12{,}000 \text{ for lengths up to 50 times least radius of gyration} & (1) \\ 15{,}000 - 57\dfrac{L}{R} \text{ for lengths from 50 to 150 times least radius of gyration} & (2) \end{cases}$$

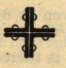
$$S_f \text{ (for soft steel)} = \begin{cases} 12{,}000 \text{ for lengths up to 30 times least radius of gyration} & (3) \\ 13{,}500 - 50\dfrac{L}{R} \text{ for lengths from 30 to 150 times least radius of gyration} & (4) \end{cases}$$

in which $S_f$ = allowable stress per square inch of column section;
$L$ = length of column, in inches;
$R$ = least radius of gyration of the section, that is the smallest radius of gyration of that section taken in any direction.

EXAMPLE.—A soft-steel column in a building is 18 ft. long; the area of the section is 14.98 sq. in. and the least radius of gyration is 1.72. What safe load will it carry?

SOLUTION.— $\frac{L}{R}=\frac{18\times 12}{1.72}=126$, about. As this is more than 30 and less than 150, formula 4 is used. $S_f=13{,}500-50\times 126$ $=7{,}200$ lb. per sq. in.; $7{,}200\times 14.98=107{,}856$ lb.


Bethlehem **H** column, no rivets.


Angle-iron column, four rows of rivets.

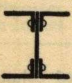
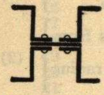
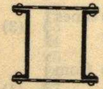
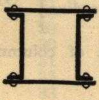


Plate-and-angle column, two rows of rivets.


Plate-and-angle column, four rows of rivets.


**Z**-bar column, two rows of rivets.


Channel-and-lattice column, four rows of rivets.


Channel-and-plate column, four rows of rivets.

**Design of Structural-Steel Columns.**—Structural-steel columns are generally formed by riveting together standard rolled shapes and plates. They should be designed so as to develop

the greatest strength for the least amount of metal used, also that they shall require the most economical expenditure of labor, both in the shop and at the structure. It is very desirable that good connections between the floor beams, girders, and columns may be made and that it shall be easy to rivet them together at the building. The columns should permit of easy splicing, so as to make a rigid connection. All connections should be designed for sufficient rivets so as to prevent failure by the shearing of the rivets. A few sections of columns commonly used are shown on page 118.

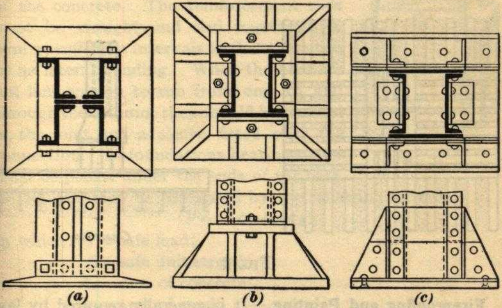



FIG. 1

**Rivets.**—The distance between rivets from center to center, is called the *pitch*. It should never be more than 16 times the least thickness of the metal of the parts joined, in the direction parallel to the stress; and never more than 32 times the thickness of metal in a direction at right angles to the line of stress. The sizes of rivets most commonly used in building construction are $\frac{3}{4}''$ and $\frac{7}{8}''$.

**Bases.**—Bases for steel columns are made of cast-iron, also of plates and angles. In Fig. 1, (*a*) represents a cast-iron base where the load is not great; (*b*) represents a cast-iron base where the load is great and must have a greater spread;

(*c*) represents a similar base to that shown in (*b*) but constructed of plates and angles.

**Grillage.**—Where it is necessary to distribute the load coming from a column over a large area, but in a small depth, a *grillage* composed of steel beams imbedded in concrete is used. For heavy loads on soil of small bearing power, three tiers of beams may be necessary, while for lighter loads and soil of greater bearing power two tiers are sufficient. Grillage work is generally buried in concrete, which stiffens it and prevents it from corroding. The plan and elevation of a grillage footing are shown in Fig. 2.

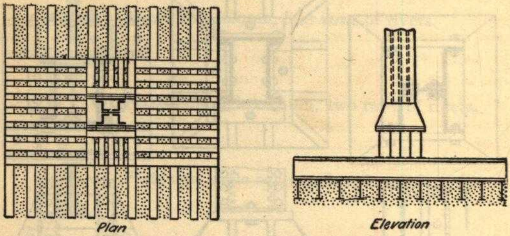



FIG. 2

**Fireproofing and Painting.**—It is generally required by law that iron and steel columns shall be protected from fire and oxidization. Two good coats of carbon or graphite paint or a good coating of Portland cement will protect the iron from rust. A covering of cement concrete poured around a column, which has been surrounded with a wooden form protects it against both corrosion and fire. A terra-cotta or brick covering is a satisfactory protection against fire. These methods are shown under the head of Fireproofing.

## REINFORCED-CONCRETE COLUMNS

In reinforced-concrete columns, the concrete to a depth of about 2 in. on all surfaces should be considered as fireproofing protection only. In the following discussion of strength and

design, therefore, the 2-in. outside surface is not included and should be put on the design afterwards. Corners of columns should be rounded, as fire more readily attacks a sharp corner. Reinforced-concrete columns may be divided into three classes: those with longitudinal reinforcement, those with hooped reinforcement, and those with steel cores.

**Longitudinal Reinforcement.**—In columns with longitudinal reinforcement, shown in Fig. 1, the unsupported length should not exceed twelve times the least width. The area of the cross-section of the steel should be between $\frac{1}{100}$ and $\frac{4}{100}$ of the area of the concrete. The reinforcement rods must be straight and tied together with wire at sufficient intervals so that there can be no lateral bending. When the bars are not long enough to run from end to end through the column, they should be squared at the joint and a sleeve fitted over the connection. In foundations bearing plates must be placed under the ends of the bars.

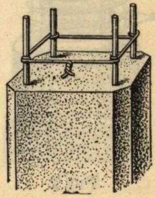


FIG. 1

The load may be calculated by the following formula

$$P = S(A_c + nA_s),$$

in which $P$ = safe load;
$S$ = safe unit stress;
$A_c$ = area of concrete;
$A_s$ = area of steel;
$n$ = ratio of modulus of elasticity of steel to that of concrete.

The ratio of the modulus of elasticity of steel to that of concrete is usually taken about 15, except for extra rich and strong mixtures when it is taken as 12.

A stress of 350 to 450 lb. is often used for concrete made of first-class materials in the proportion of one part of cement to six parts of sand and broken stone or gravel measured separately and so proportioned as to make the densest mixture.

EXAMPLE.—A column $16'' \times 16''$ is reinforced with four $\frac{3}{4}''$ square bars. What load will it carry?

SOLUTION.—First deducting 2 in. all around, the area of column is $12 \times 12 = 144$ sq. in. The area of the steel is $4 \times \frac{3}{4}$

$\times \frac{3}{4} = 2\frac{1}{4}$ sq. in. The area of concrete is $144 - 2\frac{1}{4} = 141\frac{3}{4}$ sq. in. Assuming $S = 400$ lb., the safe load is $400 \times (141\frac{3}{4} + 15 \times 2\frac{1}{4}) = 70{,}200$ lb.

**Hooped Columns.**—Hooped columns consist of concrete with steel hoops or a spiral embedded. The hoops should be protected by at least 2 in. of concrete. Only the *core*, or con-

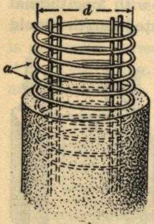



FIG. 2

crete inside the hoops is considered in the calculation. The volume of the hoops should be at least $\frac{1}{100}$ volume of the core. The vertical spacing *a*, Fig. 2, of the hoops must be less than $\frac{1}{6}$ their diameter *d*, and less than $2\frac{1}{2}$ in. Hooping should be circular and the ends of the bands united so as to develop full stress. The strength of the steel does not enter directly into the strength of the column but the hoops increase the toughness and ultimate strength of the column beyond the elastic limit. They then make the column safer and a larger unit stress can be used for the concrete. The safe load, of course, equals the safe unit stress multiplied by the area of the core. The length of hooped columns should be less than eight times the diameter of the core. Columns sometimes have both longitudinal and hooped reinforcement in which case higher stresses are used. Such columns are designed by the formula given for longitudinal reinforcement. The hooping is not considered but it permits a higher unit stress to be used and at the same time the limit of length of the column is reduced.

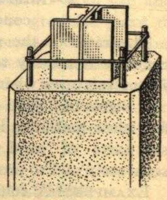


FIG. 3

**Steel-Core Columns.**—Fig. 3 shows a concrete column reinforced with a steel core and longitudinal rods. Usually in this class of columns the concrete will develop low unit stresses and caution should be used in placing any dependence on it, although it may assist the steel in resisting lateral deflection. The details of splices of the steel should conform to the standard practice for structural steel.

**Designing Reinforced-Concrete Columns.**—In all classes of reinforced-concrete columns eccentric loads require elaborate calculations not mentioned here. The design of columns of steel or reinforced concrete should be left in the hands of an engineer or experienced designer.

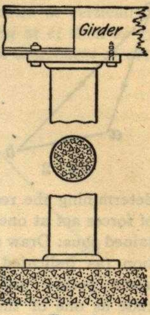



FIG. 4

### STEEL-SHELL COLUMNS

Cylinders of steel filled solid with concrete, shown in Fig. 4, are made by different concerns and are very useful where light loads are to be supported and space saved. The concrete filling prevents the column from buckling or failing as it might otherwise do in case of fire. A 6-in. column of this type, 12 ft. high, will carry a load of 25 T, and will cost, with cap and base complete, about $12.

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## ROOF TRUSSES

### PRINCIPLES OF STRESSES

**Parallelogram of Forces.**—In Fig. 1, forces *ab* of 50 lb. and *cb* of 100 lb. act at *b* in the directions shown. To find their combined action, draw *cb*, to any scale, equal to 100 lb., and *ab*, to the same scale, equal to 50 lb., each in its respective direction. Thus, if the scale is $\frac{1}{4}$ in. to 10 lb., $cb = 2\frac{1}{2}$ in., and $ab = 1\frac{1}{4}$ in. Draw *ad* parallel to *cb*, and *cd* to *ab*, intersecting at *d*; then *db*, called the *resultant*, gives the direction, and, by scaling, the amount of their combined action, which is 145 lb. The figure *abcd* forms a *parallelogram of forces*.

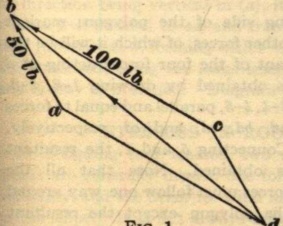



FIG. 1

**Triangle of Forces.**—Assume forces *ca* of 1,000 lb., and *ab* of 800 lb., acting at *a*, Fig. 2. Make distance *ca*, to any scale, equal to 1,000 lb., and *ab* equal to 800 lb., draw resultant *cb*, which, by scaling, is found to be 1,550 lb.; it is opposed to the direction in which forces *ca* and *ab* act around the triangle. This figure *cab* forms a *triangle of forces.*

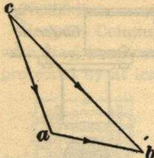


FIG. 2

**Polygon of Forces.**—The preceding diagrams may be called *polygons of forces*, but the term is usually applied to diagrams determining the resultant of several forces. When a number of forces act at one point, as at *d*, Fig. 3, their resultant is obtained thus: Draw a line parallel to and having the same direction (as indicated by the arrow points) and magnitude as one of the forces. At the end of this line, draw one parallel to a second force, having the same direction and magnitude as this second force. Continue thus until all the forces have been plotted; a straight line joining the free ends of the first and last lines will be the closing side of the polygon; mark it opposite in direction to the other forces, of which it will be the resultant. Thus, the resultant of the four forces acting at *d* is obtained by drawing *1–2*, *2–3*, *3–4*, *4–5*, parallel and equal to forces *ad*, *bd*, *cd*, and *ed*, respectively. Connecting *5* and *1*, the resultant is obtained. Note that all the forces must follow one way around the polygon except the resultant which is opposed to all the forces.

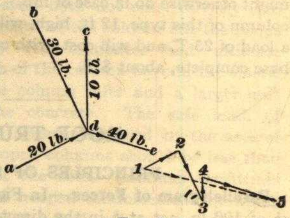


FIG. 3

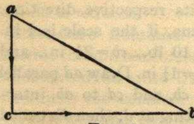
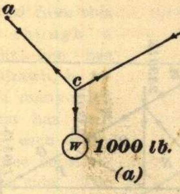


FIG. 4

**Resolution of Forces.**—As the effect of several forces may be determined by a single resultant, so may one force be

resolved into several. For example, the force *ab*, Fig. 4, may be resolved into any two directions by drawing components parallel to those directions. Thus, from *a* draw *ac* vertically, and from *b* draw *cb* horizontally, intersecting at *c*; then *ac* is the *vertical component*, and *cb*, the *horizontal component* of *ab*.

**Frame and Stress Diagrams.**—In (*a*), Fig. 5, 1,000 lb. is supported at *c* by cords *ca* and *cb*, secured at *a* and *b*. This figure, drawn to



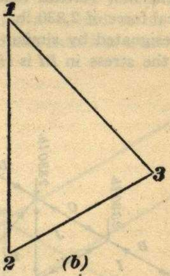




FIG. 5

scale, accurately represents the outline of the structure, and is called a *frame diagram*.

To obtain the stresses in *ca* and *cb*, draw *1–2*, in (*b*), making its length to any scale and direction represent the magnitude and action of *W*. Thus, if 1 in. = 400 lb., *1–2* = 2½ in. long, and, its direction being vertical in (*a*), it is so drawn in (*b*). From *1* draw *1–3* parallel to *ac*, and from *2* draw *2–3* parallel to *cb*; they intersect at *3*, forming with *1–2* a triangle. If *1–3* and *2–3* are measured, using the same scale as for *1–2*, the stresses *ca* and *cb* may be obtained. Diagram (*b*) is called a *stress diagram*.

## STRESSES IN ROOF TRUSSES

In designing roof trusses, two stress and two frame diagrams are generally drawn, one for the dead load, which acts vertically, and the other for wind load, usually taken as normal to the slope. It is not always necessary to draw a stress diagram for the snow load, which is also vertical, as will be explained later. That the frame and stress diagrams may be conveniently compared, the following system of lettering may be

employed: In the frame diagram, write capital letters within every space that is cut off from the rest of the figure by lines, real or imaginary, along which forces act, as in Fig. 1. Then the member or force is named from the letters of the space it divides; thus *BI* designates the lower end of the left-hand rafter; *JK*, the first vertical tension rod shown on the left; *BC*, the vertical force of 2,330 lb., etc. The stresses in these members are designated by similar small letters in the stress diagram; thus, the stress in *BI* is *bi* in Fig. 2, and in *JK* is *jk*. It is to

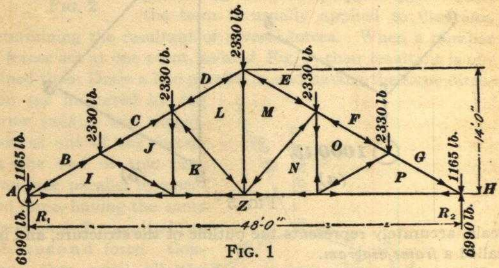



FIG. 1

be understood that wherever capital letters are used reference is made to the frame diagram; and where small letters are used, reference is made to the stress diagram.

## ANALYSIS OF HOWE ROOF TRUSS

**Stress Diagrams for Vertical Loads.**—*Dead Load.*—To explain the foregoing principles in laying out stress diagrams for roof trusses, and the determination of the amount and kind of stress in any member, the dead-load and wind-stress diagrams will be drawn for the Howe roof truss illustrated in Fig. 1. This shows the frame diagram with the dead loads, which may be figured from the tables of dead loads already given. As the loads are equal and symmetrically placed, each reaction will be one-half the total load. Letter the frame diagram as shown, and proceed with the stress diagram, Fig. 2. The external forces, which include loads and reactions, having been

determined (this should be done in every case), draw the load line *ah* vertically, as that is the direction in which the forces act. With any convenient scale, make *ab*, *bc*, *cd*, etc. equal, respectively, to the calculated forces *AB*, *BC*, *CD*, etc. The reactions *HZ* and *ZA*, being equal, *z* is located midway between *h* and *a*. Then the *polygon* of *external forces*, as it is called, is from *a* to *b*, *b to c*, *c to d*, *d to e*, and so on to *h*, where the reactions return on the load line from *h* to *z*, and from *z* to *a*, the starting point. It will be observed from this that, though a straight line has been drawn, in reality a many-sided polygon has been traced, each external force constituting a side. The internal forces, or the stresses in the truss members, may now be determined, as follows: Beginning at the left-hand joint in the frame diagram, the forces are *BI*, *IZ*, *ZA*, and *AB*. Care must be taken, in reading these forces, in the stress diagram to go around each joint in the same direction in which forces are designated in the frame diagram, namely in the direction of the movement of the hands of a watch, as shown by the curved arrow around the joint in question in Fig. 1. From *b* draw *bi* parallel to *BI*, and from *z* draw *zi* parallel to *IZ*; their intersection is at *i*, and the polygon of forces around the joint is from *a* to *b*, *b* to *i*, *i* to *z*, and *z* to *a*, the starting point. After having designated

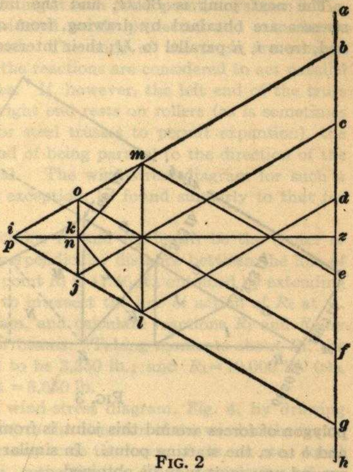



FIG. 2

all the forces at a joint in the stress diagram, always read around the polygon of forces as given above, and see that it *closes*, that is, that the last line joins the first, forming a closed figure. Also, note the direction in which the forces travel along each line in the stress diagram, and mark the same by arrowheads upon the members in the frame diagram. Arrowheads acting away from a joint, as in *IZ*, denote tension; those acting toward one, as in *BI*, denote compression.

The next joint is *BCJI*, and the lines determining the stresses are obtained by drawing, from *c*, *cj* parallel to *CJ*, and, from *i*, *ji* parallel to *JI*; their intersection is at *j*, and the

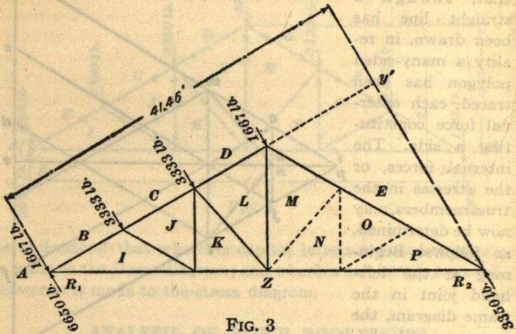



FIG. 3

polygon of forces around this joint is from *c* to *j*, *j* to *i*, *i* to *b*, and *b* to *c*, the starting point. In similar manner the stresses around any joint may be obtained.

When the apex joint is reached, the diagram begins to repeat; thus, *em* is the same as *dl*. The stress diagram is, therefore, symmetrical about a central axis and each half serves as a check on the other half.

*Snow Load.*—It is assumed that the snow load is distributed the same as the dead load. At each panel point it is taken as 2,400 lb. as against 2,330 lb. for the dead load. Therefore, each pound snow load is $2,400 \div 2,330 = 1.03$ times the dead load;

and as the distribution is the same, the stress in each member caused by the snow is 1.03 times the stress caused by the dead load. Therefore, in cases like this there is no necessity to draw a snow-load diagram as the snow-load stress in any member may be computed by multiplying the dead-load stress by 1.03.

**Stress Diagram for Wind Load.**—To determine the wind stresses, the frame diagram should be redrawn. The wind loads considered as acting at each panel point, are shown in Fig. 3. The roof is considered partly protected and a moderate wind load is assumed. The ends of the truss are secured against sliding, and the reactions are considered to act parallel to the wind pressures. If, however, the left end of the truss is secured, and the right end rests on rollers (as is sometimes the case with iron or steel trusses to permit expansion), the right reaction, instead of being parallel to the direction of the wind, will be vertical. The wind-stress diagram for such a truss will, with this exception, be found similarly to that for a fixed-end truss.

To determine reactions $R_1$ and $R_2$, let $R_1$ be the center of moments; then the perpendicular distance between the line of action of $R_2$ and the point $R_1$ is 41.46 ft., obtained by extending the left-hand rafter to intersect the line of action of $R_2$ at $y'$. Regard $Ay'$ as a beam, and calculate reactions $R_1$ and $R_2$ by the method given for beams. Taking moments about $R_1$, the reaction $R_2$ is found to be 3,350 lb.; and $R_1 = 10{,}000$ lb. (the total load) $- 3{,}350$ lb. $= 6{,}650$ lb.

Proceed with the wind-stress diagram, Fig. 4, by drawing the load line *ae* parallel to the direction of the wind in the frame diagram. Lay off to any scale the forces *ab*, *bc*, *cd*, etc., equal to *AB*, *BC*, *CD*, etc., respectively. Then, from *a* lay off *az*, equal to reaction *ZA*, or $R_1$. If the loads have been laid off accurately, *ez* should be equal to $R_2$.

The first joint to analyze is *ABIZ*. Draw *bi* parallel to *BI*; and from *z*, *zi* parallel to *IZ*; they intersect at *i*. The polygon of forces is from *a* to *b*, *b* to *i*, *i* to *z*, and *z* to the starting point *a*. Joint *BCJI* is analyzed similarly.

To analyze joint *IJKZ*: *ij* being known, the next member is *JK*; from *j* draw *jk*, parallel to *JK*. As the next member

is $KZ$, to which $kz$ is parallel, the point $k$ is located where $jk$ intersects $kz$; this completes this joint, the polygon of forces being from $i$ to $j$, $j$ to $k$, $k$ to $z$, and $z$ to $i$. The stresses at the other joints may be found in the same way as those explained. The members shown in dotted lines do not sustain wind stresses when the wind blows upon the left side of the truss.

The final joint is $DEML$, at which there is only one unknown force—the stress in $EM$. A line drawn from $e$ parallel to $EM$ should pass through $m$. This is always a test of the accuracy of the work, and if the last line does not close on the proper

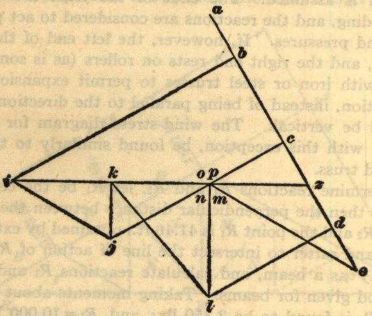



FIG. 4

point, when drawn parallel to the member it represents, the stress diagram should be redrawn, to determine whether the loads and reactions have been laid out correctly, and whether any joint or member has been omitted.

The two diagrams completed, scale, in round numbers, the stresses in each member, indicating compressive and tensile stresses by plus and minus signs, respectively.

The stresses are tabulated as follows: Remember the wind may blow from either side. As the truss is symmetrical only half of the members are mentioned. The maximum load is the combination of the dead, snow, and wind loads.

| Member | Dead Load | Snow Load | Wind Load | Maximum Load |
|---|---|---|---|---|
| *IZ* | −9,990 | −10,290 | −9,890 | −30,170 |
| *IB* | +11,560 | +11,910 | +8,540 | +32,010 |
| *CJ* | +9,250 | +9,530 | +6,660 | +25,440 |
| *JI* | +2,310 | +2,380 | +3,830 | +8,520 |
| *JK* | −1,170 | −1,210 | −1,930 | −4,310 |
| *KZ* | −7,990 | −8,230 | −6,580 | −22,780 |
| *KL* | +3,070 | +3,160 | +5,080 | +11,310 |
| *DL* | +6,940 | +7,150 | +4,770 | +18,860 |
| *LM* | −4,660 | −4,800 | −3,860 | −13,320 |
| *ZP* | −9,990 | −10,290 | −3,270 | −23,550 |
| *EP* | +11,560 | +11,910 | +5,750 | +29,220 |

Remember that the dead load always acts but the snow and wind loads only occasionally.

Where a ceiling is suspended from the underside of the truss, its weight is considered as concentrated at the lower panel points *ND PM*, *MPQRL*, etc., in the frame diagram, Fig. 5, and laid out in the order of their location in the vertical load diagram as already described. The horizontal members *DN*, *PM*, *RL*, etc. must be designed to support the transverse load as well as to take the tensile stress shown in the stress diagram.

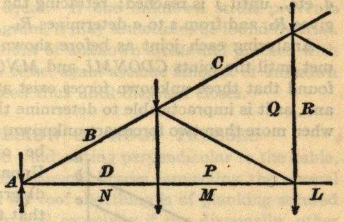



FIG. 5

## ANALYSIS OF STRESSES IN A FINK ROOF TRUSS

**Stress Diagram for Vertical Loads.**—*Dead Load.*—The Fink roof truss, shown in Fig. 6, is much used for pin-connected and structural-steel trusses.

To draw a dead-load diagram, obtain the forces acting at each panel point and draw the frame diagram for the dead

loads, as in Fig. 6. Draw, in the stress diagram, Fig. 7, the load line *abcde*, etc., locating *z* midway between *e* and *f*.

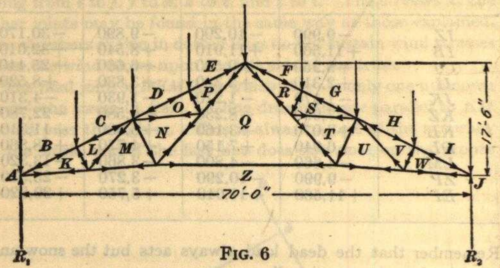



FIG. 6

The polygon of external forces will be from *a* to *b*, *b* to *c*, *c* to *d*, etc., until *j* is reached; retracing the load line from *j* to *z* gives $R_2$, and from *z* to *a* determines $R_1$.

Analyzing each joint as before shown, no difficulty will be met until the joints *CDONML* and *MNQZ* are reached. It is found that three unknown forces exist at each of these joints, and, as it is impracticable to determine the stresses graphically when more than two forces are unknown, the value of one must be otherwise obtained. Upon inspecting the frame diagram, it will be observed that the joint at *BC* is similar to *DE*; and it is reasonable to suppose that *LK* will have an equal stress with *PO*. From this it would appear that there must be an equal and like stress exerted by *LM*, to retain the foot of *LK* in position, as is exerted by *ON* to keep *PO* in place. The stresses in *ML* and *LC* being known, that in *DO* may be determined by drawing a line from *d*

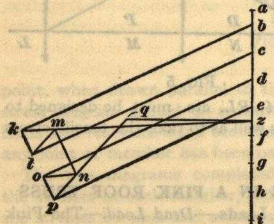



FIG. 7

parallel to $DO$, to such a point $o$ that—having drawn $on$ equal in length to $lm$—the line $nm$, parallel to $NM$, will close on $m$. The polygon of forces will be from $m$ to $l$, $l$ to $c$, $c$ to $d$, $d$ to $o$, $o$ to $n$, and $n$ to $m$, the starting point.

The joint $MNQZ$ now offers no difficulty to solution, as $mn$ has been previously determined. The final joint $OPQN$ may be solved by drawing from $p$ a line parallel to $PQ$, which will, if the diagrams have been correctly drawn, pass through $n$, and from this point will coincide with $nq$.

One-half the dead-load diagram being completed, if the loading is symmetrical, it is unnecessary to draw the other half unless as a check. The equality of the triangles $lkm$ and $pon$ greatly assist in drawing diagrams for trusses of this type.

**Method of Trial for Obtaining Third Unknown.**—The foregoing method of solving the joint $CDONML$ is applicable only when the half truss is symmetrical about the line $MN$ and when the loads are equal. If one unknown stress prevents the solution of the diagram, it may sometimes be found by trial. Thus, assume the amount of unknown stress and proceed with diagram; if it fails to close, again assume amount of unknown stress and try. Proceed thus until diagram closes.

## DETAIL DESIGN OF ROOF TRUSSES

Trusses subjected to wind, acting perpendicular to the gable, should be braced with diagonal braces connecting the several trusses. If, however, the roof sheathing is of planking secured directly to the trusses, and especially if run diagonally, other bracing may not be required. If stone gables protect the roof in a longitudinal direction, lateral bracing may in many cases be omitted.

The vertical and wind loads of a truss may be figured from tables already given. The weight of the truss is the most uncertain factor, being practically unascertainable until the design is made; hence, it is well, after designing the truss, to calculate and compare its weight with that assumed. The assumed weight is considered usually as bearing on the panel points of the upper chord and divided with the same distribution as the weight of the roof.

The stresses being determined, the members must be proportioned to sustain them. Roof trusses differ from bridge trusses in that the loads are generally statical and not suddenly applied; consequently, no impact loads are to be taken into account. Cast iron is seldom used in roof trusses, and is never used with a factor of safety less than 10, unless the load creates compressive stress only, in which case a somewhat smaller factor may be used. The factor of safety of all materials is a matter of judgment, and may be altered as the designer's experience dictates.

Tension members are liable to fail at the least cross-section which is where the screw thread is cut; therefore, sometimes the screw ends of long rods and bolts are enlarged, or upset so that the cross-section at the root of the threads will be at least as large as elsewhere. If only a few bolts are required, this upsetting may not pay. Allowance must be made for diminution of cross-section by bolt or rivet holes. To determine the net section required in any tension member, divide the total stress in the member by the allowable tensile stress of the material.

In proportioning a compression member, the length of which is not over eight or ten times the diameter or least side, the cross-section may be figured by dividing the stress by the allowable direct unit compressive stress. If, however, the length exceeds these dimensions, the members must be regarded as columns, and figured as such. If a member is subjected alternately to compression and tension, its section should be somewhat increased over that required to sustain either stress.

The purlins are so placed that the load acts directly on the joint; this procedure prevents direct bending of the rafter. In the case of some wooden trusses this procedure puts the purlin directly over the nut of a tension rod; therefore, the rod should be arranged so that it can be tightened up if required from the bottom and it will not come loose on top. In other cases where this condition occurs, sometimes the purlin is moved off the bolt. This is not recommended unless the rafter is designed to withstand combined bending and compression because if the purlin is not placed directly over a joint it causes bending in the rafter. Sometimes, also, when the joints are far apart, an additional purlin is placed halfway between joints.

This likewise causes bending and the designing of a member to carry this combined stress is more or less complex.

In designing the joints, all ways in which the joint can fail must be investigated. In proportioning short wooden struts that butt against the upper and lower chords, it will often be found that the size of the strut is not governed by the stress in the strut but by the allowable compression of the end grain of the strut on the side grain of the chord. In connecting members by pins, the bending of the pin is often more important than the shear. The deflection as well as the strength must often be considered, especially when the truss is plastered underneath or under the rafters.

In designing any structure, and especially roof trusses, the following points should be carefully observed: Proportion all parts of a joint so that the maximum strength will be realized throughout, in order that one part will not be likely to yield before another. Weaken as little as possible the pieces connected at a splice. Give sufficient bearing surface to bring the compression on the surface well within the safe limits, so that there will be no danger of crippling plates or crushing the ends of members before their maximum strength is realized.

Distribute rivets and bolts so as to give the greatest resistance with the least cutting away of other parts. See that the central axis of every member coincides as nearly as possible with the line of action of the stress.

Examine all sections and parts for tensile, compressive, transverse, and shearing stresses.

Finally, bear constantly in mind that the strength of a structure depends on the strength of its weakest part, and that the failure of a single joint may be as fatal to the life of a structure as though a member were insufficient.

A close study of the details of the trusses shown in Figs. 1 and 2, in connection with the foregoing explanations of principles, will give a general idea of how such parts are designed.

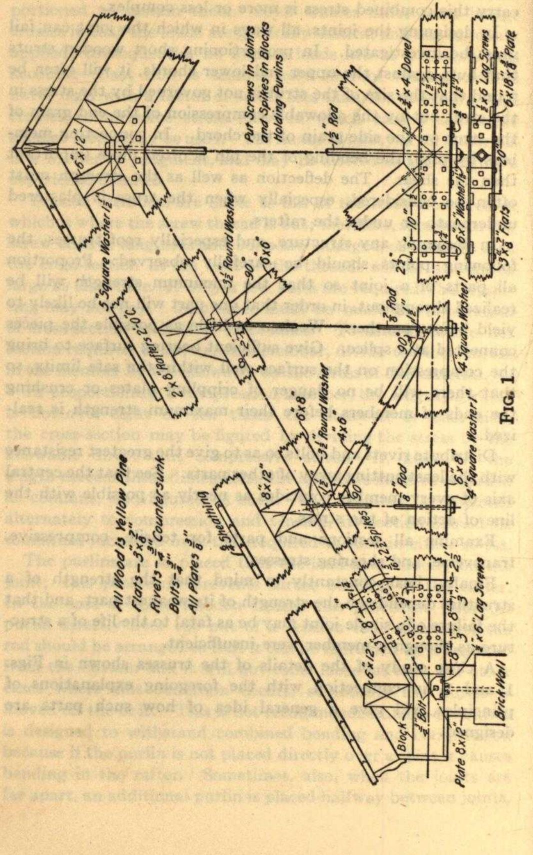

All Wood is Yellow Pine
Put Screws in Joints and Spikes in Blocks Holding Purlins
Brick Wall
Block
Sheathing
Round Washer
Square Washer
Rod
Dowel
Lag Screws
Plate

FIG. 1

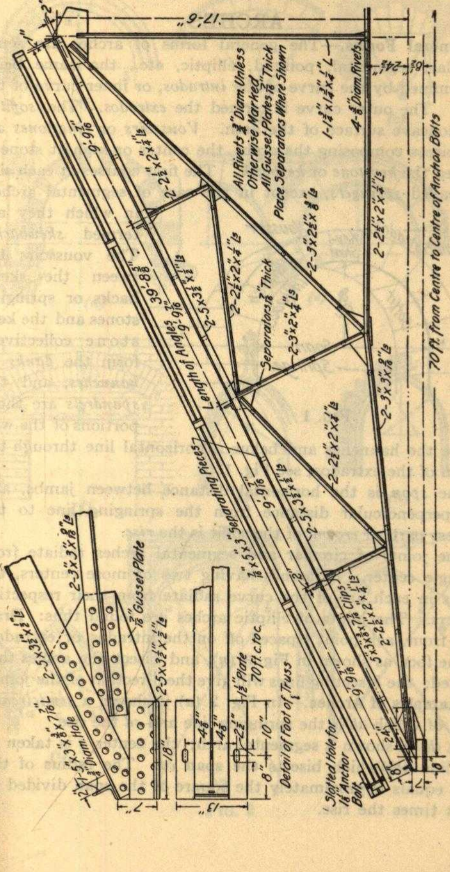

All Rivets 3/4" Diam. Unless Otherwise Marked
All Gusset Plates 7/16" Thick
Place Separators Where Shown
70 ft. from Centre to Centre of Anchor Bolts
Length of Angles 39'-8 5/8"
Separating Pieces
Separators 7/16" Thick
Gusset Plate
Detail of Foot of Truss
1/2" Plate
70 ft. c. to c.
Slotted Hole for 1 1/8" Anchor Bolt
Clips
Diam. Hole

FIG. 2

## ARCHES

**General Forms.**—The general forms of arches are semicircular, segmental, pointed, elliptic, etc., the name being determined by the curve of the *intrados*, or inner curve of the arch. The outer curve is termed the *extrados*. The *soffit* is the concave surface of the arch. *Voussoirs* or *ringstones* are the pieces composing the arch; the center or highest stone is termed the *keystone* or *keyblock*. The first courses at each side are called *springers*, except in the case of segmental arches, in which they are termed *skewbacks*. The voussoirs between the skewbacks or springing stones and the keystone collectively form the *flanks* or *haunches*, and the *spandrels* are those portions of the wall above the haunches and below a horizontal line through the crown of the extrados; see Fig. 1.

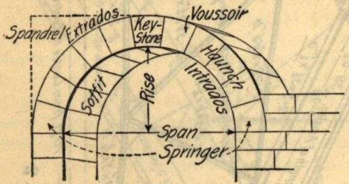


FIG. 1

The *span* is the horizontal distance between jambs, and the perpendicular distance from the springing line to the highest part, or *crown*, of the soffit is the *rise*.

The joints of circular and segmental arches radiate from a single center. In arches having two or more centers, the joints in each arc of the curve radiate from their respective centers. The joints of elliptic arches are found thus: Draw lines from each point (spaced off on the intrados or extrados) to the foci, as shown in Fig. 3 (*n*), and bisect the angles thus formed; the bisecting lines will give the direction of the joints.

**Examples of Arches.**—In Fig. 2 (*a*) is shown a *semicircular arch*, of which *ab* is the springing line and *cd* the rise.

In (*b*) is shown a segmental arch; the center *a* is taken on the line *ab*, which bisects the span *cd*. The radius of this arch equals approximately the square of the span divided by eight times the rise.

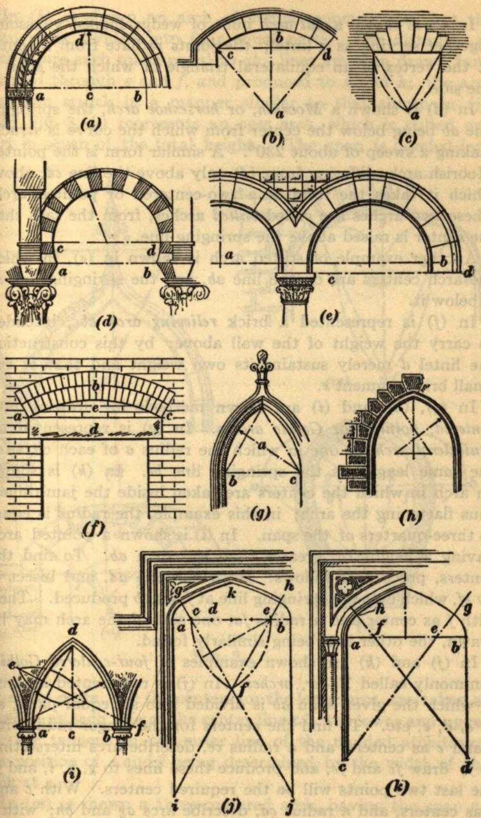



FIG. 2

In (*c*) is shown a ***flat arch*** built of wedge-shaped voussoirs, together serving as a lintel; the joints radiate from a center at the vertex of an equilateral triangle of which the span is one side.

In (*d*) is shown a ***Moorish***, or ***horseshoe arch***, the springing line *ab* being below the center from which the curve is struck, making a sweep of about 230°. A similar form is the pointed Moorish arch, differing from (*d*) only above the line *cd*, above which it takes the form of a two-centered or pointed arch. These two arches are called ***stilted*** arches, from the fact that the center is raised above the springing line.

Another example of stilted arch is shown in (*e*), in which the arch centers are on the line *ab*, and the springing line *cd* is below it.

In (*f*) is represented a brick ***relieving arch*** *abc*, intended to carry the weight of the wall above; by this construction the lintel *d* merely sustains its own weight and that of the small brick segment *e*.

In (*g*), (*h*), and (*i*) are shown methods for drawing ***two-centered, pointed***, or ***Gothic arches***. In (*g*) is represented an ***equilateral arch***, or one in which the radius *a* of each curve is the same length as the springing line *bc*. In (*h*) is shown an arch in which the centers are taken inside the jamb lines, thus flattening the arch; in this example, the radius is equal to three-quarters of the span. In (*i*) is shown a pointed arch having a height *cd*, greater than the span *ab*. To find the centers, proceed as follows: Draw the line *ad*, and bisect it by *ef*, which cuts the springing line at *f*, on *ab* produced. Then with *f* as center and a radius *fa*, one side of the arch may be drawn, the other half being similarly found.

In (*j*) and (*k*) are shown examples of ***four-centered Gothic***, commonly called ***Tudor, arches***. In (*j*) is represented an arch in which the given span *ab* is divided into six equal parts, as at *c*, *d*, *e*, etc. To find the centers for the longer radii, with *c* and *e* as centers, and a radius *ce*, describe arcs intersecting at *f*; draw *fc* and *fe*, and produce these lines to *g*, *h*, *i*, and *j*; the last two points will be the required centers. With *c* and *e* as centers, and a radius *ca*, describe arcs *ag* and *bh*; with *i* and *j* as centers, and a radius *ih*, describe the arcs *hk* and *gk*.

In (*k*) is shown an arch of similar construction, but the span *ab* is divided into four equal parts. The distances *ac* and *bd* are each made equal to *ab*; lines are then drawn from *c* and *d* through *e* and *f*, and produced to *g* and *h*; the arcs are then struck in a manner similar to that shown in (*j*).

In Fig. 3, (*l*) represents an *ogee arch*, which is stilted one part in seven of the total height. The span is divided into

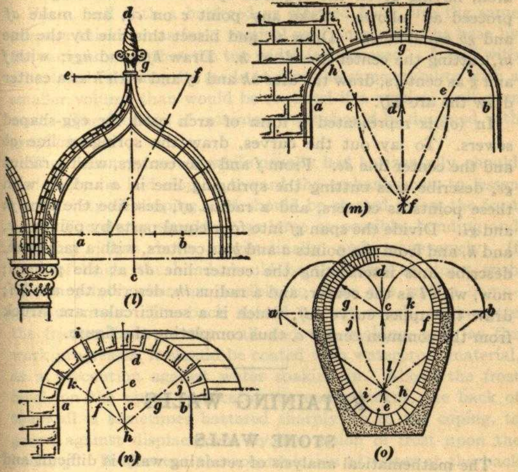



FIG. 3

six equal parts, and the centers for the lower arcs are taken at *a* and *b*, at each side of the center line *cd*; the lower and upper arcs are tangent on the outer line of the molded architrave, the position of *e* and *f* being determined by the width of the neck at *g*.

In (*m*) is shown a three-centered arch, having the span *ab* given. To lay out this arch, divide *ab* into four equal parts,

as at *cde*. From *a* and *b* as centers, with a radius *ae*, describe the arcs *ef* and *cf*, intersecting on the center line *fg*. From *c* and *e* as centers, with a radius *ca*, describe the arcs *ah* and *bi*; and from *f* as a center, with the radius *fh*, describe the arc *hgi*, completing the figure.

In (*n*) is shown a three-centered skew arch, which closely approaches an elliptic curve in form. To construct the arch, having given the required span *ab* and the height *cd*, proceed as follows: Take any point *e* on *cd*, and make *af* and *gb* equal to *ed*. Draw *fe*, and bisect this line by the line *hi*, cutting the center line *dc* at *h*. Draw *hfk* and *hgj*; with *f* and *g* as centers, draw the arcs *ak* and *bj* and with *h* as a center draw the arc *kdj*.

In (*o*) is represented a form of arch used for egg-shaped sewers. To lay out the curves, draw the springing line *ab* and the center line *de*. From *f* and *g* as centers, with a radius *gc*, describe arcs cutting the springing line in *a* and *b*; with these points as centers, and a radius *af*, describe the arcs *fh* and *gi*. Divide the span *gf* into four equal parts by points *j*, *c*, and *k*, and from the points *a* and *b* as centers, with a radius *ak*, describe arcs intersecting the center line *de* at the point *l*; now, with *l* as the center, and a radius *lh*, describe the arc *hei*; draw the upper curve *gdf*, which is a semicircular arc struck from the common center *c*, thus completing the figure.

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## RETAINING WALLS

### STONE WALLS

The mathematical analysis of retaining walls is difficult and filled with uncertainties. Moreover, retaining walls although carefully and elaborately designed often fail. For this reason empiric rules are often used. Probably the best series of empiric rules is that presented by John C. Trautwine in his well-known "Civil Engineers' Pocketbook." These rules, with slight modifications, are as follows: For a vertical wall resting on a foundation of masonry suitably enlarged for a proper distribution of the load on the soil, with the top of the fill leveled off at the top of the wall, and with the backing

deposited loosely, as when dumped from carts, the ratio of the thickness to the height of the wall should be .35 for a wall of cut stone, or of first-class large-ranged rubble, in mortar, or of concrete; .4 for a wall of good common rubble or brick, in mortar; and .5 for a wall of dry rubble. If the backing is deposited in layers well compacted, the thickness may be slightly reduced. It is not, however, customary to reduce the thickness on this account.

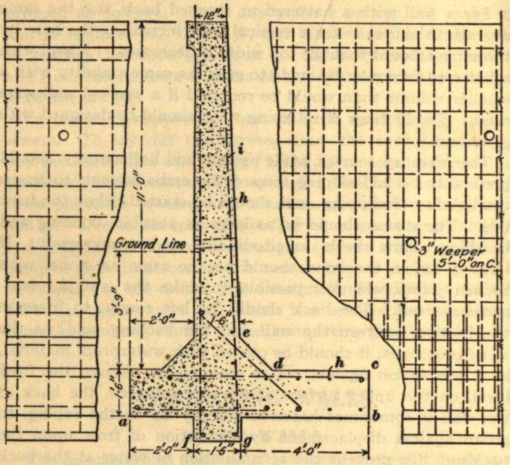
For a wall with a battered or stepped back, use the same average thickness as for a vertical wall, increasing the base by the same amount that the top width is decreased. A wall with a battered face may be made to give the same stability with a smaller volume than would be required if a vertical wall were used. The footings of retaining walls should be designed with great care.

The masonry courses, while usually laid horizontally, should preferably be laid sloping toward the embankment, to lessen the liability of slipping, and should be started below the frost line. The stones should be as large as possible, bonding and breaking joints both longitudinally and transversely. If built of brick, the bond should be the same as stone, with broken joints, wherever possible, to make the wall a homogeneous mass. The back should be left rough, to increase the friction between the wall and the backing, and, as the work progresses, it should be coated with waterproof material, as a precaution against water soaking in. Above the frost level, on the upper surface of the embankment, the back of the wall is sometimes battered sharply up to the coping, to guard against displacement by the action of frost upon the backing. To prevent the accumulation of water at the back of the wall, open-jointed drain tiles should be laid at proper levels along the back of the wall, to collect all surface and rift water, and discharge the same through small openings, called *weepers*, left in the wall for that purpose. The natural drainage of the soil should never be dammed up by a wall.

If the fill tends to hold moisture, sometimes a layer of broken stone, gravel, or the like is placed next to the wall to act as a drain.

## REINFORCED-CONCRETE RETAINING WALL

The accompanying figure shows a reinforced-concrete retaining wall. Retaining walls of this type usually fail in one of four ways: by the wall breaking, by the soil yielding, by the wall tipping, and by the wall sliding. In the figure, the wall is prevented from breaking by the steel rods that are embedded in the concrete. The foundation of the wall is spread out, as shown at *ab*, to distribute the pressure on the




soil so that the wall will not fail by the second method. Tipping is prevented in two ways: First, the *toe a*, which is the point around which the wall tends to turn, projects so far in front that the weight of the wall has a large leverage to hold the structure in place; moreover, the filling rests on the shelf *edc*, which must be lifted before the wall can turn about the toe. Sliding is prevented by the weight of the wall and the weight of the filling on the shelf *edc*. If there is still a tendency to

slide, the projection *fg* may be added to offer additional resistance.

The rods shown at *h* are shrinkage rods running longitudinally along the wall to prevent cracks due to shrinkage. Thin walls shrink more in proportion than thick ones and require more rods. The rods shown at *i* carry the tension due to the bending of the wall proper. There is sometimes danger, especially when smooth rods are used, of their pulling through the concrete. For that reason it is recommended that they be anchored at the ends, either by hooking them around other rods or by putting a nut on the end.

# MATERIALS OF MASONRY CONSTRUCTION

## STONE

*Granite* is the most valuable stone where strength is required. Its colors range from almost white to dark gray; and from light pink to deep red. It can be quarried in very large pieces and is susceptible of a high polish. Owing to its hardness, it is very costly to dress, and its use is limited to the most expensive kinds of buildings. Granite being very dense and compact, absorbs but little water, and hence is valuable in damp situations. Exposed to fire, it disintegrates at a temperature of from 900° to 1,000° F., being less durable in this respect than fine-grained compact sandstones.

*Limestone* is a very common building stone, and, when compact, is very durable. The color is generally light gray, sometimes it is deep blue, and occasionally cream or buff. It is usually quite absorptive and becomes dirty quickly. Under intense heat, it is converted into lime. Limestone must be well seasoned before use, to get rid of the quarry water.

*Marble* is crystallized limestone. It is comparatively scarce and consequently expensive, hence is not often used in constructional work except for columns, but is extensively used for decorative purposes.

*Sandstones*, in general, are excellent building stones, and include some of the most durable and beautiful stones used in exterior construction. On account of the ease with which they can be worked and because of their wide distribution throughout the country, they are more extensively used than any other stones. They are capable of resisting great heat, and the better kinds absorb only small quantities of water. A stone containing much iron pyrites is apt to become discolored, due to the formation of rust, hence the stone should be carefully examined to see that pyrites are not present. Sandstones are found in a great variety of colors, shades of gray, brown, pink, red, drab, and blue being common.

*Slate*, although not strictly a building stone, is largely used for the roofs of buildings, templates, blackboards, steps, and sanitary purposes. Its valuable qualities are its strength, toughness, and non-absorptive character, as well as its tendency to split into sheets.

**Selecting Stones for Masonry.**—The densest and strongest stones are generally the most durable. A fresh fracture, when examined under a magnifiying glass, should be clear and bright, showing well-cemented particles. When a good stone is tapped with a hammer, it gives out a ringing sound. The absorptive quality of a stone may be tested by noting the increase in weight after soaking in water for 24 hr. One that increases 5% or more should not be used. For ordinary building purposes, tests of crushing strength are unnecessary, for if stone is of good quality the strength is generally very much in excess of any probable loads.

## BRICK

*Bricks* are more extensively used in building than any other material except wood, and in their durability and acid and fire-resisting qualities are superior to most building stones. They are made in many varieties, such as common brick, face brick, firebrick, paving brick, molded brick, hollow brick, glazed brick, enameled brick, etc.

*Common bricks* should be thoroughly burned, hard, straight, true, and uniform in size. If two bricks are struck together,

they should give out a ringing sound; if the sound is dull, the bricks are of an inferior quality. The color should be red, and bricks that are too light, or salmon-colored, are apt to prove too soft for use. A brick should not absorb more than 10% of its weight of water. The standard size of common bricks may be given as $2\frac{1}{4}'' \times 4'' \times 8\frac{1}{4}''$, but the size varies in different localities.

*Face bricks* are made in a variety of colors, textures, sizes, and shapes. The term face brick generally refers to bricks that have been pressed into a mold by machinery before burning and are carefully shaped with square corners, smooth surfaces, sharp edges, and are of uniform size. A face brick, at present very popular, is characterized by a more or less rough surface and a great variety of pleasing colors. Face bricks are generally burned hard and absorb very little water.

*Firebricks* are used where great heat is to be resisted, as in fireplaces, furnaces, flues, etc. They should be porous, so as to be poor conductors of heat. The size is about $9'' \times 4\frac{1}{2}'' \times 2\frac{1}{2}''$ and the weight about 7 lb. per brick. They are of a light cream color and are laid up with a mortar made of fireclay like that of which they are made.

*Paving bricks* are made by burning a mixture of shale and fireclay to vitrification. They should have a crushing strength of about 8,000 lb. per sq. in. and should absorb very little water. They are used for paving driveways and roads.

*Molded bricks* are pressed bricks made in special ornamental forms, and are used in building up cornices, belt-courses, arches, etc.

*Hollow bricks* are made of brick clay and of the same sizes as common bricks but are hollow. They are built up on the inside face of brick walls to take the place of furring and to exclude dampness.

*Enameled bricks* are used for the interiors of kitchens, bathrooms, swimming pools, and wherever a hard sanitary surface is desired. The American size is $8\frac{1}{4}'' \times 2\frac{5}{16}'' \times 4''$, and the English size $8\frac{7}{8}'' \times 2\frac{7}{8}'' \times 4\frac{3}{8}''$.

*Wash bricks* are common bricks that have a pitted surface such as would be caused by their being exposed to the action of rain while in a soft state.

## TERRA COTTA

*Terra cotta* is classed as architectural and structural.

*Architectural terra cotta* is made from carefully selected clays of a better quality than is required for bricks. After the clay has been specially prepared and tempered, it is formed into the desired architectural form by being pressed into plaster molds; though if only one piece is desired the clay may be modeled to the design required by the hand of the sculptor direct, to which process the clay readily lends itself. The terra-cotta blocks, after being pressed, are thoroughly dried and then placed in muffled kilns and are burned at from 1,800° to 2,300° F., for about 12 days.

This material is always manufactured to meet the special architectural requirements of each building, as to design, color, texture, etc. All manufacturers furnish estimates based on architects' drawings and specifications. These drawings should include all elevations, floor plans, roof plan, longitudinal and transverse sections, also steel drawings and details if available. Terra cotta, if concealed behind porches, railings, and inside of entrances should be clearly indicated and dimensions given; also special mention should be made of such terra-cotta interior work as may not be readily discernible from the main elevations.

If not otherwise specified, most manufacturers base estimates on standard terra cotta, which is also commonly described as limestone color. Other colors and finishes are, however, used extensively, especially enameled and glazed finishes in a variety of shades. Within a few years polychrome (or many colored) terra cotta has begun to occupy a prominent place in architectural decoration both for interior and exterior use where colored embellishment is desirable.

Terra cotta should be specified as *standard, matt glazed, full glazed*, or *polychrome*. The tooling of the surface should be clearly indicated as, "four cut to the inch," or "six cut to the inch," "eight cut to the inch," "dragged heavy," "dragged light," or "smooth," etc. All glazed work is made with a smooth surface. If any special or unusual color is required, such as that of a certain granite, or other stone or special brick,

the color required should be stated explicitly, and a sample furnished to be matched. If polychrome effects are required, they should be indicated clearly on drawings, and fully and explicitly described in the specifications.

No standard weight per cubic foot can be fixed for architectural terra cotta, as this factor differs widely with size, shape, and ornamentation of blocks. Neither is it possible to quote prices for architectural terra cotta on any fixed basis because of the great variety of design and other requirements. Economy of manufacture, however, is greatly assisted by a considerable repetition of identical features in the same building.

All work near the eye should have joints ground on a rubbing bed to a uniform true joint of not over $\frac{3}{16}$ in. All upper-story work should be carefully fitted and set with a joint of not over $\frac{3}{8}$ in. The terra-cotta manufacturer will always supply a setting diagram, to scale, numbered to correspond with the numbers marked on the terra-cotta blocks, and these numbers should be followed exactly in setting the material.

The part of terra cotta bonded in the wall should be thoroughly backed up with brick, or filled with concrete, so that the strength of walls is equal throughout. Outside shell and partitions of terra-cotta blocks should be made of uniform thickness, ranging from 1 in. in small pieces, to $1\frac{1}{4}$ in. in large pieces, and placed approximately 6 in. on centers; 1-in. cubes taken from commercial work should show a minimum compressive strength of 5,000 lb. to the sq. in. In cases where terra cotta is supported on or engages structural steel, the manufacturer will provide slots for said steel in the terra cotta and will furnish such schedules or drawings as are required for the manufacture of this steel. All bonds must be properly tied into the brickwork, blocks to be either self-supporting or supported by iron as shown on setting drawing. In no case should depth be less than 4 in.

The time required to manufacture architectural terra cotta varies according to the character of work; 8 wk. is ordinarily considered a minimum time for first shipment of plain work after receipt of working drawings fully approved by architect. Manufacturers of architectural terra cotta claim for this

material infinite possibilities in the matter of form; a surface finish that is impervious; unlimited scope in color effects; lightness of weight combined with great tensile strength; fire-resisting qualities that are testified by the kiln heat in burning, and the durability that is characteristic of all well-burned clay products.

*Structural terra cotta* is used in the construction of outside walls, floors, partitions, and for the protection of columns, girders, etc., from fire. There are three general kinds: dense tiling, porous terra cotta, and semiporous terra cotta.

*Dense tiling* is made of fireclay mixed with other clays, molded into shape under great pressure, and burned at a temperature of from 2,000° to 2,500° F. It is very strong, somewhat brittle, and a thoroughly fireproof material.

*Porous terra cotta* is made by mixing from 25% to 35% of sawdust with pure clay. The sawdust is destroyed when the terra cotta is burned and the result is a light, porous material that can be cut with a saw or edge tool and into which nails and screws can be driven.

*Semiporous terra cotta* is made of fireclay with which is mixed about 20% of ground coal. The coal aids in burning the material and leaves it somewhat porous. As a fire-resistant this material is considered superior to either porous terra cotta or dense tiling.

## LIME

*Lime* is made by burning limestones, that have the requisite properties, in kilns. When properly burned, quicklime should possess the following qualities: It should be in hard lumps, free from cinders or clinkers, and should slake readily in water forming a smooth, impalpable paste, without residue. It should dissolve in soft water if enough is added.

Lime weighs about 66 lb. per bu., or about 53 lb. per cu. ft. One barrel of lime, weighing 230 lb., will make about $2\frac{1}{4}$ bbl., or .3 cu. yd. of stiff paste. In 1-to-3 mortar, 1 bbl. of unslaked lime will make about $6\frac{3}{4}$ bbl. of mortar; or 1 bbl. of lime paste will make about 3 bbl. of mortar. For a 1-to-2 mortar, about 1 bbl. of quicklime to 5 or $5\frac{1}{2}$ bbl. of sand are used.

*Hydrated lime* is quicklime thoroughly slaked by the aid of machinery and may be used in place of common lime.

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## CEMENTS

*Cement* may be divided into three general classes: Portland, natural, and puzzolan (also called *pozzuolana*). The relative importance of each cement is indicated by the order in which it is named.

*Portland cement* may be defined as the product resulting from the process of grinding an intimate mixture of calcareous (containing lime) and argillaceous (containing clay) materials, calcining (heating) the mixture until it starts to fuse, or melt, and grinding the resulting clinker to a fine powder. It must contain not less than 1.7 times as much lime, by weight, as it does of those materials that give the lime its hydraulic properties, and must contain no materials added after calcination, except small quantities of certain substances used to regulate the activity or the time of setting.

*Natural cement* is the product resulting from the burning and subsequent pulverization of an argillaceous limestone or other suitable rock in its natural condition, the heat of burning being insufficient to cause the material to start to melt.

*Puzzolan cement* is a material resulting from grinding together, without subsequent calcination, an intimate mixture of slaked lime and a puzzolanic substance, such as blast-furnace slag or volcanic scoria.

Portland cement may be distinguished by its heavy weight, slow rate of setting, and greater strength. Natural cement is characterized by lighter weight, quicker set, and lower strength. Slag cement is somewhat similar to Portland but may be distinguished from it by its lilac-color, lighter weight, and the greater fineness to which it is ground.

The color of the different grades of cement is variable, but in certain cases it is distinctive. Portland cement is a dark-bluish or greenish gray; a light yellow color may indicate underburning. Natural cement ranges in color from a light straw, through the grays to a chocolate brown. Slag cement is gray

with usually a tinge of lilac. In general, however, the color of cement is no criterion of its quality, except when a certain brand shows a variation in color, thus indicating a lack of uniformity in the raw materials or in the process of manufacture. Cement is packed either in wooden barrels or in cloth or paper bags, the latter being the form of package most commonly employed. A barrel of Portland or of slag cement contains the equivalent of four bags, while but three bags of natural cement equals a barrel.

In proportioning mortar or concrete by volume, the common assumption is that a bag of Portland cement occupies .9 cu. ft.

## SAND

The *sand* should be free from clay or earthy materials, and should preferably be pit sand. Sea sand should never be used unless thoroughly washed, as the salt in the sand causes efflorescence. Pulverized brick, cinders, furnace slag, etc. are sometimes used as substitutes for sand with good results. The addition of a small quantity of brick dust to ordinary lime-and-sand mortar seems to give it the property of setting under water, and also prevents disintegration when the mortar is exposed to the elements.

## MORTAR

In mixing *lime mortar*, a bed of sand is first made in a mortar box, and the lime is distributed as evenly as possible over it. The lime is slaked by pouring on water and covering with a layer of sand or, preferably, a tarpaulin, to retain the vapor given off. Sufficient water should be used at the start; if more is added later, it chills the hot lime and makes it lumpy. Too much water makes the paste thin, weak, and slow in drying. Additional sand is then added, if necessary, until the mortar contains the proper proportion, which is usually 3 of sand to 1 of lime. The bulk of the mortar will be about one-eighth greater than that of the dry sand alone, so that 20 cu. ft. or 16 bu. of sand, and 3 cu. ft. or 2.4 bu. of quicklime, will make about $22\frac{1}{2}$ cu. ft. of mortar.

Cement-and-lime mortar is made by adding the required amount of lime paste to cement mortar.

A good method of mixing cement mortar is as follows: After one-half the quantity of sand is spread over the bottom of the mortar box, spread the cement evenly over the sand, and then put on the remainder of the sand. Thoroughly mix the dry materials either by hoe or by shovel; then add water to as much of the mass as is required for immediate use, and mix this portion until it has the uniform consistency of a stiff paste. The quantity of water required depends on the cement used,

**PROPORTION OF MORTAR IN MASONRY**

| Kind of Masonry | Per Cent. of Mortar | |
|---|---|---|
| | Minimum | Maximum |
| Brickwork, coarse, $\frac{1}{2}$-in. to $\frac{5}{8}$-in. joints | 35 | 40 |
| Brickwork, ordinary, $\frac{1}{4}$-in. to $\frac{3}{8}$-in. joints | 25 | 30 |
| Brickwork, pressed, $\frac{1}{8}$-in. joints | 10 | 15 |
| Ashlar, courses 12 in. to 20 in. high, joints $\frac{3}{8}$ in. to $\frac{1}{2}$ in. | 7 | 8 |
| Ashlar, courses 20 in. to 32-in. high, joints $\frac{1}{4}$ in. to $\frac{3}{8}$ in. | 5 | 6 |
| Rubble, coarse, not dressed | 33 | 40 |
| Rubble, roughly dressed | 25 | 30 |
| Rubble, well-dressed, coursed | 15 | 20 |

but it is better to have an excess than a deficiency. Owing to the rapidity of setting, only small lots of this mortar should be mixed at a time.

In winter, a small proportion of lime is sometimes mixed with the cement, as the heat generated in slaking is supposed to prevent freezing until the cement has set. Salt is often added for the same purpose, the quantity being about one-fifth of 1% of the weight of the water used in making the mortar for each 1° F. below the freezing point. Salt is objectionable, however, as it causes efflorescence. By using salt or by warming the materials, masonry may be safely laid with Portland-cement mortar at a temperature of 20° F.

Although founded on actual work, the accompanying tables are not intended to furnish more than fairly close approximations, as there are so many uncertainties about mortar and masonry that very accurate estimates cannot be made.

EXAMPLE.—How much cement and sand will be required to obtain 8.5 cu. yd. of 1-to-3 Portland-cement mortar?

SOLUTION.—According to the table 1 cu. yd. of a 1-to-3 Portland-cement mortar requires 2.42 bbl. of cement; therefore, 8.5 cu. yd. will require $8.5 \times 2.42 = 20.57$ bbl. of cement. Also, as 1 cu. yd. of a mixture of this kind requires 1.01 cu. yd. of sand, the quantity of sand required will be $8.5 \times 1.01 = 8.59$ cu. yd.

**MATERIALS REQUIRED PER CUBIC YARD OF MORTAR**

| Kind of Mixture | Portland Cement Barrels | Loose Sand Cubic Yards |
|---|---|---|
| 1 to 1 | 4.95 | .65 |
| 1 to 2 | 3.28 | .88 |
| 1 to 3 | 2.42 | 1.01 |
| 1 to 4 | 1.99 | 1.06 |
| 1 to 5 | 1.62 | 1.11 |
| 1 to 6 | 1.34 | 1.15 |
| 1 to 7 | 1.18 | 1.17 |
| 1 to 8 | 1.05 | 1.18 |

EXAMPLE.—How many barrels of cement and cubic yards of sand will be required for laying 100 cu. yd. of rubble masonry in 1-to-3 cement mortar?

SOLUTION.—The table Proportion of Mortar in Masonry says that the minimum percentage of mortar in coarse rubble is 33; hence, for each cubic yard of masonry $\frac{1}{3}$ cu. yd. of mortar is required. According to the table Materials Required per Cubic Yard of Mortar, a 1-to-3 mortar requires, per cubic yard, 2.42 bbl. of cement and 1.01 cu. yd. of sand; or 1 cu. yd. of rubble requires $\frac{2.43}{3}$ bbl. of cement and $\frac{1.01}{3}$ cu. yd. of sand; and for 100 cu. yd. the quantities are 81 bbl. of cement and 34 cu. yd. of sand.

## CONCRETE

Concrete should be made by spreading the wetted aggregate evenly over a layer of cement mortar (made as described under Mortar) in a box or on a platform, and mixing the materials thoroughly. The *aggregate* is usually broken stone, not over a specified size; but gravel, broken brick, etc., may be substituted. Whichever is used should be free from dirt, and well sprinkled before mixing. The pieces should be of different sizes, so that the smaller pieces will fit in the spaces between the larger. The word aggregate describes the broken stone, gravel, etc. that is added to the mixture of cement and sand to form concrete. Some authorities include in this term the sand with the stone, gravel, etc.

A good proportion for concrete is 1 part of cement, 2 parts of sand, and 4 parts of broken stone, properly graded, these quantities being generally sufficient to fill all the voids.

**MATERIALS REQUIRED TO MAKE 1 CU. YD. OF RAMMED CONCRETE**

| Mixture | Cement Barrels | Sand Cubic Yard | Broken-Stone Aggregate Cubic Yard |
|---|---|---|---|
| 1 to 2 to 4 | 1.46 | .44 | .89 |
| 1 to 3 to 5 | 1.11 | .51 | .85 |
| 1 to 3 to 6 | 1.01 | .46 | .92 |
| 1 to 3 to 7 | .91 | .42 | .97 |
| 1 to 4 to 7 | .83 | .51 | .89 |
| 1 to 4 to 8 | .77 | .47 | .93 |

In laying, concrete should not be dumped from a considerable height, as the thoroughness of the mixture will be destroyed. It should be spread in layers of, say, 8 in. in thickness, and tamped enough to compact the mass well, the surface of each layer being left rough, to form a better bond with the succeeding one.

The strength of concrete increases considerably with age. For example, a Portland cement concrete 1 mo. old will sustain

a load of about 2,400 lb. per sq. in., and if it is 6 mo. old, it will sustain about 3,700 lb. per sq. in.

The quantities of materials required for different grades of concrete vary with different materials and conditions. The values in the preceding table are taken from the larger and more complete table compiled by Mr. Edwin Thacher. The aggregate in this table consists of stones not larger than 1 in. with the dust screened out.

# MASONRY CONSTRUCTION

## FOUNDATIONS

Before beginning a structure, the character of the soil should be investigated. For ordinary work, this can be done by boring—using a 2-in. auger—at short intervals, around the site. The auger will bring up samples sufficient to determine the character of the soil. But boring can be dispensed with, for the usual run of buildings, when the bearing power is known by experience with loads in adjacent structures, or by the examination of near-by excavations.

A level bed of rock makes the best possible foundation; sand and gravel rank next; clay is safe for moderate loads if kept dry; quicksand should be removed if possible; and soft, marshy ground should be piled, or the footings spread enough to reduce the pressure to safe limits. Important structures should not be built upon made ground that is formed of garbage, waste earth, etc., though small buildings may be erected upon it. For small buildings, however, good made ground is safe to build on. The table on page 81 gives the loads that different kinds of soils will carry.

If water is encountered in excavating foundations, careful provision must be made for its removal by means of suitable drains. The frost line, or depth to which ground becomes frozen, must be taken into account, and foundations must be started below it; otherwise, they may be cracked and heaved out of place. This depth varies from 3 ft. to 6 ft., or more, according to the severity of the climate.

Foundations should not be laid on a sloping bed, owing to the liability of slipping. Nor should the walls be built partly on rock and partly on earth, for the weight causes the earth to settle, and the wall, being carried by the rock only, will be unstable. When a level bed cannot be otherwise obtained, concrete may be advantageously used for this purpose. If the natural surface is rough, the better will concrete adhere to it. In fact, concrete should be used much more than it is for foundation work. For buildings of moderate weight, erected on soft, clayey soils, the bearing power of the latter may often be considerably improved by spreading layers of sand, gravel, or broken stone, and pounding it into the soil. Or, the soil may be compacted by driving short piles, say 6 ft. long and 6 in. in diameter, as close together as necessary; from 2 to 4 ft. apart is generally close enough. The results will be better if the piles are drawn out and the holes filled with sand, well compacted.

## PILES

When *piles* are driven closely to confine puddle in a coffer dam, or for preventing the fall of an earth bank, they are called *sheet piles*, and consist of planking from 2 to 6 in. thick, the bottoms being cut at an angle, which forms a driving toe. This toe tends to keep the pile close up to the adjacent one. The heads are kept in line by securing longitudinal stringers, or wales, to them by spiking or bolting. Steel sheet piling is also used especially for heavy work. It consists of structural shapes, either of common section or of special shapes, made interlocking, or connected together with clips or other devices.

Piles that sustain loads are called *bearing piles*. They may be square or round in section, but are usually round, and are from 9 to 18 in. in diameter at the top. They may be used either with or without the bark. White pine or spruce is suitable where the ground is soft; where it is firmer, Georgia pine may be used to advantage. Where the soil is very compact, hardwoods, such as oak, hickory, ash, elm, beech, etc., are used. Piles are usually driven at intervals of from $2\frac{1}{2}$ to 4 ft. between centers, according to the nature of the soil and the weight to be sustained.

The following formula gives the safe load for a pile driven by a drop hammer:

$$W = \frac{2wh}{k+1},$$

in which $W$ = safe load, in pounds;
$w$ = weight of hammer, in pounds;
$h$ = fall of hammer, in feet;
$k$ = penetration of pile at last blow (head of pile in good condition, not split or broomed), in inches.

Assuming that the fall of the drop hammer is 30 ft., its weight 2,000 lb., and the penetration at the last blow $\frac{1}{2}$ in., or .5 in., the safe load is

$$\frac{2 \times 2{,}000 \times 30}{.5+1} = \frac{120{,}000}{1.5} = 80{,}000 \text{ lb., or } 40 \text{ T.}$$

Where piles are spaced at 3 ft. between centers each way, the foundation area will safely sustain a load of from 3 to 5 T. per sq. ft., and when spaced at $2\frac{1}{2}$ ft. between centers each way, the load may be increased to from 5 to 7 T. per sq. ft.

Where the soil is very hard, it is necessary to shoe the piles with cast or wrought iron, to make them drive more easily. In order to preserve the heads from brooming and splitting, wrought-iron hoops, from $\frac{1}{2}$ to 1 in. thick, and 2 or 3 in. wide, are used.

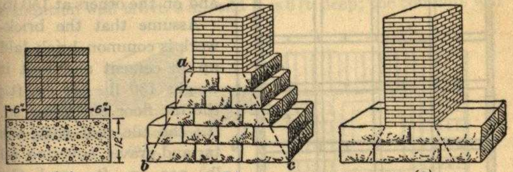
When driven, the piles are carefully sawed off to the same level, usually below the water-line, and capped by cross-rows of timbers or planking, forming a grillage upon which the masonry is laid. Sometimes large flat stones are laid directly on several of the piles. This latter method is good, provided the stones are set so as to bear evenly on the piles, without much pinning up by spalls, because the spalls are liable to be crushed. The heads of the piles may also be embedded in concrete for 2 or 3 ft., which makes a very satisfactory foundation.

**Concrete Piles.**—Concrete piles are now used to a considerable extent in foundation work. They are not subject to decay and to the attacks of worms and insects as are wooden piles.

## FOOTINGS

*Footings* should be designed for the load they are to carry, with the object of producing a uniform settlement in all parts of the building. They evidently should not be as wide under an opening as under a solid wall, and when the openings form a considerable proportion of the wall area, that part of the footings under them should be omitted, the weight being transmitted by arches or beams to the footings under the sides of the openings. This caution is very important, as a majority of cracks in masonry are probably due to continuous footings where little or none are needed. If one portion of the foundation, as, for example, that under a tower, carries much more weight than another part, its width should be proportionately increased.

In designing footings, the center of gravity of the walls should be placed a little inside of the center of gravity of the footings. For cottages and small buildings a footing such as




(a) (b) (c)

FIG. 1

shown in Fig. 1 (*a*) is a thoroughly satisfactory one. It consists of a 12-in. layer of concrete, 12-in. wider than the thickness of the wall.

Footing courses should be battered or stepped up, making the angle *abc*, view (*b*), about 60°. The load then becomes well distributed over the base. If the footings are laid as shown in (*c*), the projections are liable to break off at the edges of the wall, and the load will be unevenly carried by the soil.

**Method of Proportioning Footings.**—To show the method of proportioning footings (and of figuring loads in structures),

the area of the footings for a $45' \times 60'$ brick warehouse, shown in Fig. 2, having five stories and basement, a tar-and-gravel roof, tile arch floors, and roof, and without partitions, will be determined. There are two rows of columns, spaced $14\frac{1}{2}$ ft. apart longitudinally and transversely. The walls of the building are 75 ft. high, 25 ft. being 20 in. thick, and 50 ft., 16 in. thick. As the basement floor rests directly on the ground, its load will not be considered. The floor loads on the first and second stories will be taken at 200 lb. per sq. ft., and on the others at 150 lb.

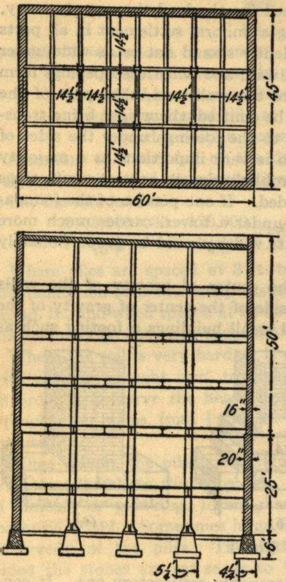



FIG. 2

Assume that the brickwork is common brick laid up in cement and that it weighs 130 lb. per cu. ft.; the tile floor 80 lb. per sq. ft.; the tile roof with the tar-and-gravel covering 60 lb. per sq. ft.; and the snow load is 20 lb. per sq. ft. Then, for each foot in length of the side walls, the load is:

DEAD LOAD

*Walls—*

$1\frac{2}{3} \times 1 \times 25 = 41.7$ cu. ft.

$1\frac{1}{3} \times 1 \times 50 = 66.7$ cu. ft.

$108.4 \times 130$ .................... = 14,092 lb.

*Floors—*

[80 (lb. per sq. ft.) $\times 1 \times 7\frac{1}{4}$] $\times 5$ ............. = 2,900 lb.

*Roof—*

60 (lb. per sq. ft.) $\times 1 \times 7\frac{1}{4}$ ................ = 435 lb.

LIVE LOAD

*On Floors*—

[200 (lb. per sq. ft.) $\times 1 \times 7\frac{1}{4}$] $\times 2 = 2{,}900$

[150 (lb. per sq. ft.) $\times 1 \times 7\frac{1}{4}$] $\times 3 = 3{,}262$ . . . . . = 6,162 lb.

*Wind*, neglected on nearly flat roof

*Snow*—

20 (lb. per sq. ft.) $\times 1 \times 7\frac{1}{4}$ . . . . . . . . . . . . . . . . . . = 145 lb.

Total dead and live load = 23,734 lb.

Assume that, upon testing, the soil has been found to be moderately dry clay. As the average safe load for this soil is 3 T. per sq. ft., dividing the total load, 23,734, by 6,000, there results $3\frac{3}{4}$ ft. as the approximate width of the footings for the side walls. If the foundation walls are made 6 ft. deep, and battered 1 in. per ft., the top width will be $2\frac{3}{4}$ ft. Thus far the weight of the foundation wall has not been considered. Having obtained the approximate width of the footing, its weight can now be computed. The average width of the foundation wall is 3 ft. 3 in., and it is 6 ft. deep; the contents will

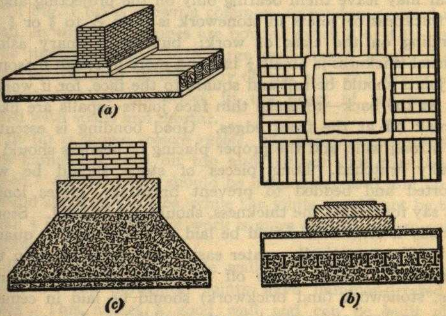



FIG. 3

be $19\frac{1}{2}$ cu. ft. per ft. of length; the walls are good limestone rubble, weighing 150 lb. per cu. ft., so that the total weight

will be 2,925 lb. Adding this to 23,734 lb. and dividing by 6,000 lb., the unit load, the final result is about $4\frac{3}{4}$ ft. as the width of the footing. The footings for the end walls and piers may be similarly figured.

**Spread Footings.**—Spread footings are used on compressible soils to bring the load per square foot within the safe bearing power of the soil. They may be made of timber, in wet soils, alternate courses being laid transversely; of layers of **I** beams or rails, laid in concrete; or of concrete with several transverse courses of twisted iron rods (a patented method). These are shown in Fig. 3 (*a*), (*b*), and (*c*). In the first two cases, it is necessary to figure the safe length of the projecting portion.

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# STONE MASONRY

## NOTES ON STONEWORK

Stone being the stronger material, a wall should have as much stone and as little mortar as possible. Contact of the stones in bed joints is not advisable, as the shrinkage of the mortar may leave them bearing only on the projecting angles. The thickness of joints in stonework is from $\frac{3}{16}$ to $\frac{1}{2}$ or $\frac{5}{8}$ in., depending on the class of work; but for ordinary ashlar, the usual thickness is about $\frac{1}{4}$ in., and more in rough masonry. Bed joints should be full and square to the face, for if worked slack at the back—to make thin face joints—spalls are likely to break off at the front edges. Good bonding is essential for a strong wall, and the proper placing of headers should be carefully watched. Long pieces of stone should be well supported and bedded to prevent breaking; pieces longer than, say four times the thickness, should not be used. Stone, especially if stratified, should be laid on its natural or quarry bed, for if set vertically, water easily penetrates between the layers, and, freezing, splits off the outer ones. For damp places, stonework (and brickwork) should be laid in cement mortar or lime-and-cement mortar, while in dry positions good lime mortar may be used. In laying stone, the mortar should be kept back about 1 in. from the face of the wall; otherwise spalls may be broken off, owing to the outside

mortar hardening more rapidly than that in the interior, settlement bringing the pressure on the hard layer. This precaution is very important in the case of lug sills, band courses, etc. The joints may be pointed, after the wall is built, with some non-staining mortar. When the temperature has reached the freezing point, it is unsafe to dress-cut unseasoned stone in the open air, as the quarry sap in the stone freezes, and the stone may be fractured during the process of cutting.

When using cement grout, the brick or stone should not be wet; they will then absorb the water in the grout, and also some of the cement, thus increasing the adhesion. Grout is usually made of ordinary mortar, thinned to the consistency of cream. If an extra strong wall is required, a 1-to-1 mortar may be used.

## CLASSES OF STONE MASONRY

**Rubble Masonry.**—Rubble masonry is used for rough work, such as foundations, backing, etc., and although frequently consisting of common field stone, quarried stone should be used where possible, as better bonding and bedding can be secured.

In Fig. 1 (*a*) is shown a common- or random-coursed rubble wall, in which the stones are bonded every 3 or 4 ft., as at *a*. The angles are laid with large well-shaped stone, the long sides alternating; in the body of the wall, the stones are set irregularly, the interstices in the heart of the wall being filled with spalls and mortar.

In (*b*) is shown *cobweb rubble*, the quoins, or corner stones, are hammer-dressed on top and bottom, but may be rock-faced. All the joints should be hammer-dressed and no spalls should show on the face, while the joints should not be thicker than ½ in. This class of work is more expensive than common rubble.

In (*c*) is shown a rubble wall with brick quoins; in this work all the horizontal joints have hammer-dressed level beds. This makes a good wall and can be built cheaply when the stone used splits readily.

In (*d*) is shown regular-coursed rubble; in this work continuous horizontal joints are run at intervals of 15 to 18 in.

in the height, as at *abc* and *def*. No attention need be paid to uniformity of height in the different courses, but the beds should be made as nearly parallel as possible.

As already stated, rubble walls are used for rough work

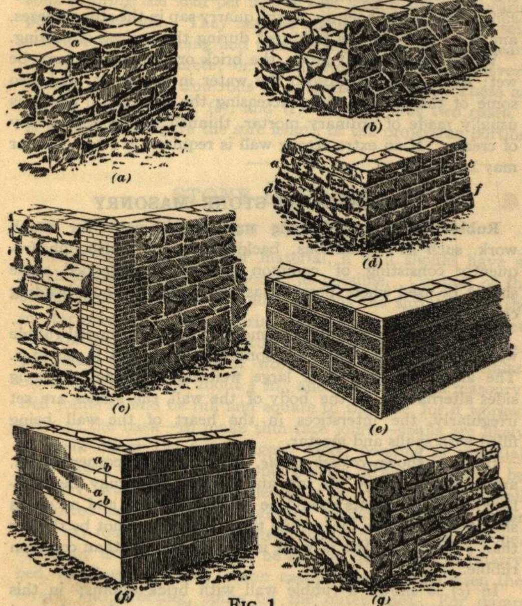



FIG. 1

and are built up of common field stone or stones from a convenient quarry. These stones are roughly shaped with a hammer. Rubble masonry varies in strength with the shape and character of the stone. If the stone has a marked strati-

fication and splits up into flat layers, a very strong wall can be built with it. If, on the contrary, boulders or field stone are used, they should be dressed to form flat beds or else a very weak wall will result. Rubble walls require a large amount of mortar, but mortar may be saved if spalls or chips of stones are bedded in the mortar between the larger stones. The stones should be of such a size that they can be handled by two men.

A through stone, or bond stone, should be built in the wall for every six superficial ft. of wall surface; or stones, two-thirds the thickness of the wall, may extend from the opposite faces of the wall and overlap each other once in every 4 superficial ft. of wall surface.

**Ashlar.**—When the outside facing of a wall is of cut stone, with the joints carefully cut and squared, it is called *ashlar*, regardless of the manner in which the face of the stone is finished.

*Regular-coursed* ashlar, shown in Fig. 1 (*e*), has pieces uniform in height and the courses continuous. Stones about 12 in. high and from 18 to 24 in. long are the cheapest, both as to first cost and in expense of handling. The illustration shows the stone bush-hammered with tooled draft lines. A good effect is produced by making the courses of two different heights, as shown in (*f*), the courses *a* being from 10 to 18 in. high and composed of *facers*, while the courses *b* are from 5 to $7\frac{1}{2}$ in. high and constitute bonding courses. The latter should be at least 4 in. wider than the thickest stones used in the facing courses.

*Broken ashlar* consists of blocks truly squared but of different sizes, forming a broken range or course. As this masonry is in itself irregular, it is well adapted to buildings of irregular plan or of irregular sky line. Broken ashlar is finished in various ways. The simplest, though not the least effective, finish is the plain rock face, shown in (*g*). The block must first be cut true and square all around, forming beds and vertical joints, after which straight lines are drawn around the edges, about 2 in. from the face of the block. A wide pitching chisel is then used along these lines, knocking off the surplus material. The smallest stone used should not be less

than 4 in. in height, nor the largest greater than 16 in. The bond, or the lap of one stone over another, should be at least 6 in. for the smaller stones and 8 in. for the larger. The length of any block should not be less than $1\frac{1}{2}$, nor more than 4, times its height. The hardest kinds of rock are best suited for masonry of this sort, which is, perhaps, the most common kind of ashlar used in modern building.

Ashlar should be carefully bonded, either by using courses of different thicknesses, or, if the ashlar is only 2 to 4 in. thick, by means of anchors, such as shown in Fig. 2 (*a*) and (*d*).

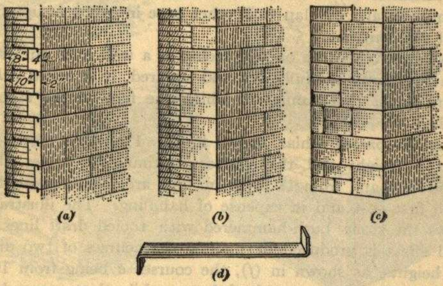



FIG. 2

When the courses are 4 in. to 8 in. thick, a good bond to the backing may be had by using these thicknesses in alternate courses, as in (*b*) and (*c*). When the backing is of brick, the joints in it should be as thin as possible.

The stones in ashlar with brick backing should be designed to be a certain number of brick courses in height so that it will bond well, as in (*b*). Very thin ashlar must not be considered in determining the strength of walls, but the backing must be made sufficiently strong, independently of the ashlar, to support all loads. Ashlar should be set in a mortar made with a non-staining cement, such as La Farge, or a white Portland cement. The backs of the stones are frequently coated with a waterproof paint before being set.

All projecting courses, such as cornices, lintels, sills, etc., should be beveled on top, and have a drip, such as shown at *a*, Fig. 3 cut on the under side to prevent water from soaking into the joints. Lug sills should be beveled only between the jamb lines, the ends being cut level, as at *b*, thus keeping out water from the joint between brick and stone, and also forming a more secure bearing for the wall.

The top of exposed walls should be covered by coping, in long pieces, and have the vertical joints well filled with good

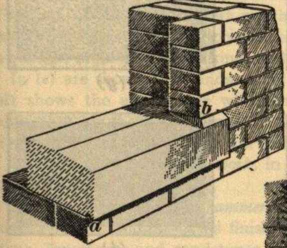



FIG. 3

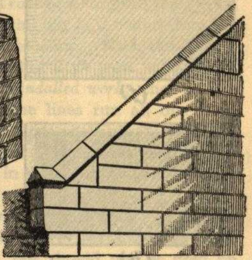


FIG. 4

mortar. Gable copings should be anchored very firmly, either by iron dowels or ties, or by bond stones, the latter method being shown in Fig. 4.

When the wall is finished, the mason starts at the top of the building and points all the joints, and cleans the stonework with brushes and a dilute solution of muriatic acid. During the progress of the work all projecting members such as cornices, belt-courses, and sills should be protected, by boarding, from injury due to falling pieces of building material.

## STONE FINISHES

Some of the tools used in making the finer finishes for stonework are shown in Fig. 1. The *crandall* (*a*) consists of a wrought-iron bar, flattened at one end, with a slot, $\frac{3}{8}$ in. wide and 3 in. long, in which ten double-headed points, made

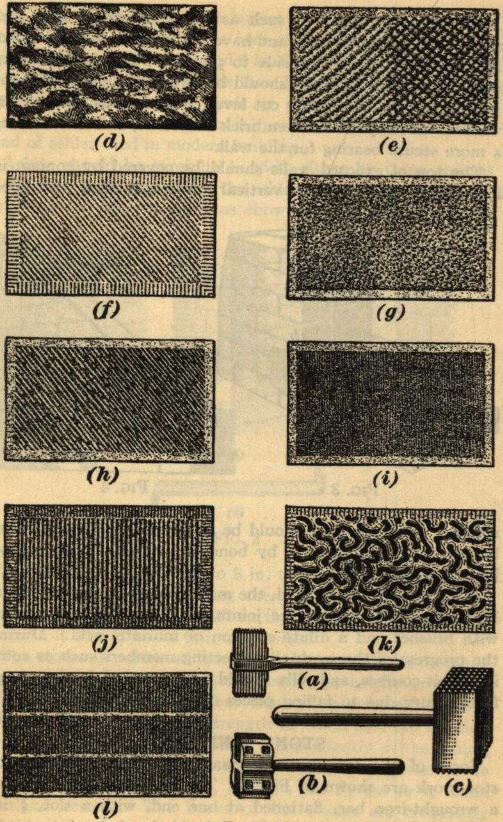



FIG. 1

of $\frac{1}{4}$ in. square steel about 9 in. long, are fastened by means of a key. It is used to finish the surface of sandstone after it has been worked with the tooth-axe or chisel.

The *patent hammer* (*b*), made of several thin blades of steel, ground to an edge and held together with bolts, is used for finishing granite or hard limestone.

The *bush hammer* (*c*), from 4 to 8 in. long and 2 to 4 in. square, has its ends cut in pyramidal points. This hammer is used for finishing limestone and sandstone after the surface has been made nearly even.

In (*d*) is shown the appearance of *rock-faced* or *pitch-faced work*. The face of the stone is left rough, just as it comes from the quarry, and the edges are pitched off to a line. Rock-faced finish is cheaper than any other kind, as but little work is required.

In (*e*) are shown two kinds of *crandalled work*; that on the left shows the appearance when the lines run all one way, while that on the right shows the lines crossing. This finish is very effective for red Potsdam and Longmeadow sandstones.

In (*f*) is shown *broached work*, in which continuous grooves are formed over the surface.

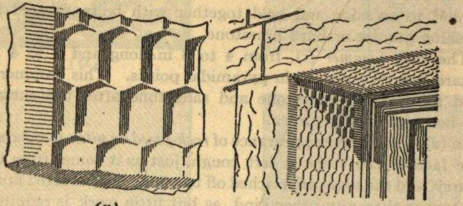
In (*g*) is shown *bush-hammered work*, which leaves the surface full of points. This finish is very attractive on bluestone, limestone, and sandstones, but should not be used on very soft stones.

In (*h*) is shown *pointed work*; that on the left half of the stone being *rough-pointed*, while the right half is *fine-pointed*. In the rough-pointed work, the point is used at intervals of 1 in. over the stone, while in the fine-pointed, the point is used at every $\frac{1}{2}$-in. of the surface.

In (*i*) is shown the *patent-hammered finish*, generally used on granite, bluestone, and limestone. The stone is first dressed to a fairly smooth surface with the point, and then finished with the patent hammer. The fineness of the work is determined by the number of blades in the hammer. For U. S. government work, 10 cuts per in. are generally specified, but 8 cuts per in. is good work.

In (*j*) is illustrated *tooled work*. For this finish, a chisel from 3 to $4\frac{1}{2}$ in. wide is used, and the lines are continued across the width of the stone to the draft lines.

In (*k*) is shown *vermiculated work*, so called from the worm-eaten appearance. Stones so cut are used in quoins and base courses. This dressing is very effective, but expensive.

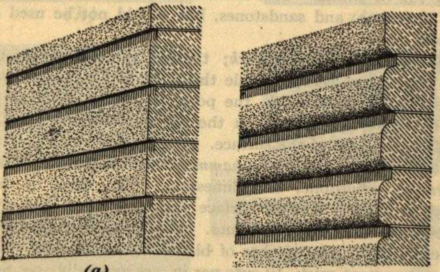


(*a*) (*b*)

FIG. 2

In (*l*) is shown *droved work*, similar to tooled work, except that the lines are broken, owing to the smaller size of the chisel used. It is less expensive than tooled work.

When a smooth finish is desired, the surface of the stone is *rubbed*. This is best done before the stone becomes seasoned.



(*a*) (*b*)

FIG. 3

The finish shown in Fig. 2 (*a*), known as *scale work*, is obtained by cutting out rows of shallow flutes between the drafts of

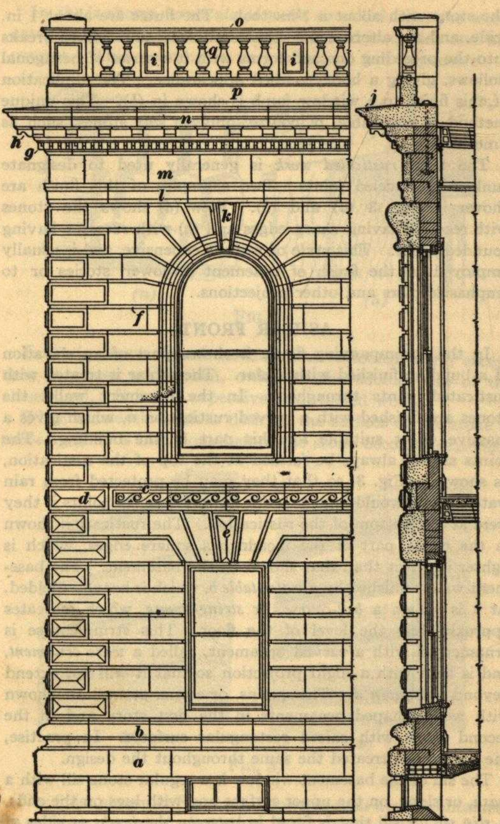
the stone with about a 1-in. tool. The flutes are about 1 in. wide, and are alternated so that each successive course breaks into the preceding one and forms with it a series of hexagonal hollows, giving a honeycombed appearance. The application of this finish to a window jamb is shown in (*b*). This unique method is applicable, of course, only to soft stones, such as limestone.

The term *rusticated work* is generally used to designate sunken or beveled joints. Two examples of this finish are shown in Fig. 3 (*a*) and (*b*). View (*a*) shows the stones with recesses having sharp edges and (*b*) with recesses having rounded edges. This style of work is expensive, and is usually employed in the finish of basement or lower stories or to emphasize piers and other projections.

## ASHLAR FRONT

In the accompanying figure is shown part of an elevation of a building finished with ashlar. The ashlar is treated with rusticated joints throughout. In the basement walls, the stones are finished with a curved rustication *a*, which gives a massive effect suitable for this part of the building. The joints should always be formed at the top of the rustication, as shown in Fig. 3, so that they may be protected from rain water, which would tend to work its way into the joints if they were at the bottom of the rustication. The rustication shown in the upper part of the façade has square edges, which is lighter in effect than that shown on the basement. The basement wall is finished by a *water-table b*, which is heavily molded. At *c* is shown a *belt-course*, or *string-course*, which indicates approximately the level of the floor. This string-course is ornamented with a carved ornament, called a *wave ornament*, and is kept with a slight projection so that it will not extend beyond the *quoin d*. The quoins, or corner stones, are shown with wedge-shaped ornaments in the first story and in the second story with raised rectangular surfaces. In practise, the quoins are treated the same throughout the design.

The sill of the basement window is a regular stone sill with a *wash*, or slope, on the upper surface and with lugs on the ends. A *slip sill*, or sill that is fitted in between the *jambs* or sides of


o
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a

the opening, is shown for the first-story window. The basement window has a straight stone lintel above it; this is shown backed up with brickwork that is supported on iron beams. This backing should be made strong enough to support the wall over the window.

Over the first-story window is a flat arch of stone. In order that the *soffit*, or under surface of the arch, may not appear to be depressed or sag in the middle it is generally *cambered*, or built with a slight curve that is higher in the middle. The keystone *e* is ornamented the same as the quoin *d*.

The second-story window has a semi-circular arch over it and the rustications are brought down to the window opening. A molded stone trim or architrave is set in this opening, giving the window a rich effect. The horizontal line through the center of the arch is kept above the nearest horizontal joint *f*, which makes the arch appear slightly stilted and consequently more effective. The keystone *k* is emphazised by a *bracket* or *console*.

The entablature, consisting of an *architrave*, *l*, *frieze*, *m*, and *cornice*, *n*, is about one-fifth of the distance between the top of the water-table and the bottom of the architrave. The cornice is of the Corinthian type and contains dentils *g* and modillions, *h*. The cornice should be covered with a flashing of lead or copper, which will protect the upper surface from the effects of water and prevent the washing out of the joints. This flashing is let into a *reglet*, or groove, *j* as near the front edge of the cornice as it is safe to cut it.

The balustrade above the cornice is shown with a high base *p*, otherwise it would be cut off from view by the projecting cornice. The base of the balustrade should be flashed by letting the flashing into grooves cut into the stone. The balusters *q* are turned and separated into groups by blocks, *i*. The top rail *o* and the bottom rail should be cut with washes and the balusters should be doweled into both rails with metal dowels.

The stones are anchored to the backing as shown, and the upper stones of the cornice should be anchored down to the wall by bolts, which extend into the joints between the stones. Washers are fitted to both ends of these bolts.

# BRICK MASONRY

## THICKNESS OF WALLS

The thickness of walls in brick masonry is a matter determined by experience. The laws of various cities specify the minimum allowable thickness, under various conditions. In Figs. 1 and 2, diagrams are shown giving the minimum thicknesses of walls allowed in different classes of buildings in the City of New York. The buildings are divided into two general classes, dwellings and warehouses, and the walls of the buildings in the warehouse class are required to be 4 in. thicker than those in the dwelling class. In the design of walls for buildings in various localities, copies of the laws in vogue should be obtained and studied.

The wall shown in Fig. 1 (*a*) is for side and party walls only, as well as for a building not over 20 ft. in width and 55 ft. in length. The remaining sections are for walls not over 26 ft. apart and having a length of not over 105 ft. without cross-walls or buttresses.

The thickness of walls is modified by the number of window, door, or other openings, and of flues, and chases. The New York Code says "If any horizontal section through any part of any bearing wall in any building shows more than 30 percentum of flues and openings, the said wall shall be increased in thickness 4 in. for every 15 percentum in excess of 30 percentum."

Ashlar, when used to face a brick wall, shall not be less than 4 in. in thickness. If the ashlar is made 4 in. thick, it is not counted in the effective thickness of the wall but must be thoroughly bonded to the wall. If, however, the ashlar is not less than 8 in. thick and bonded into the brickwork by longer stones every few courses, it may be included in the thickness of the wall in estimating the strength.

All walls faced with brick in running bond must be 4 in. thicker than shown in Figs. 1 and 2. All non-bearing walls in dwellings may be 4 in. less in thickness than shown in Fig. 1, provided they are not less than 12 in. thick.

*Foundation walls*, or walls built below the curb level, shall be made, if of brick, 4 in. thicker than the total thickness of

the wall immediately above, to a depth of 12 ft. below the curb level. For every additional 10 ft. deeper, these walls shall be

### WALLS FOR DWELLING HOUSES

Under this heading the following buildings shall be included:

Dwellings
Asylums
Apartment houses
Convents
Club houses
Dormitories
Hospitals
Hotels
Tenements
Parish buildings
Laboratories
Schools
Studios
Lodging houses

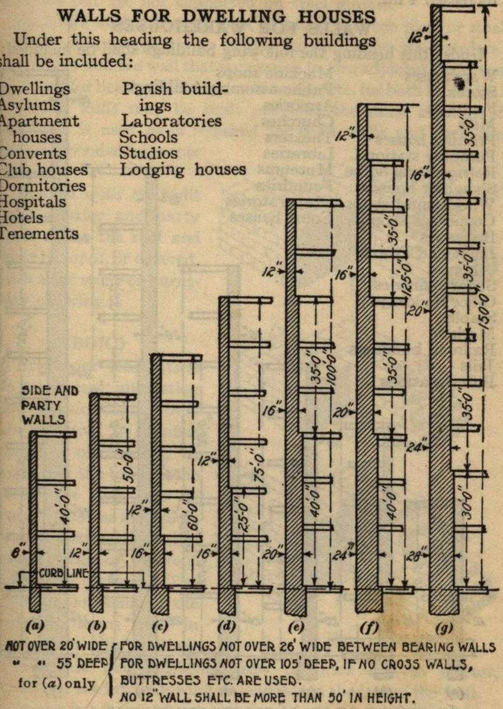



FIG. 1

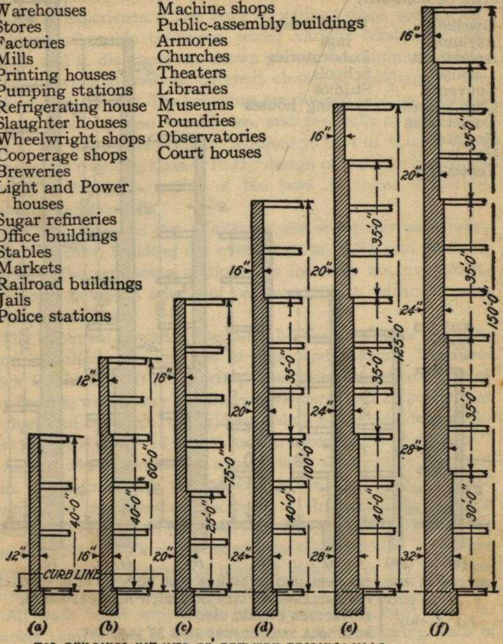
increased 4 in. If of rubble stone, or Portland cement concrete, these walls shall be at least 8 in. thicker than the wall next

above, to a depth of 12 ft. below the curb level, and for every 10 ft. or fraction thereof of additional depth they shall be increased 4 in.

## WALLS FOR WAREHOUSES

Under this heading the following buildings shall be included:

Warehouses
Stores
Factories
Mills
Printing houses
Pumping stations
Refrigerating house
Slaughter houses
Wheelwright shops
Cooperage shops
Breweries
Light and Power houses
Sugar refineries
Office buildings
Stables
Markets
Railroad buildings
Jails
Police stations
Machine shops
Public-assembly buildings
Armories
Churches
Theaters
Libraries
Museums
Foundries
Observatories
Court houses




FOR BUILDINGS NOT OVER 25' BETWEEN BEARING WALLS
" " " " 105' DEEP [IF NO CROSS WALLS, BUTTRESSES ETC. ARE USED.]

Fig. 2

## DEFINITIONS

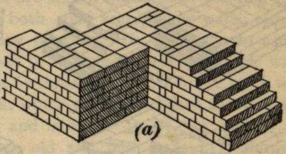
*Curtain walls* are walls that are built between piers or steel columns but are not supported on steel girders.

*Inclosure walls* are walls built of brick between piers or steel columns and are partly or wholly supported on steel girders.

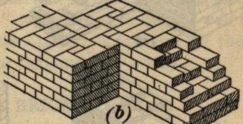
*A Party wall* is a wall that is common to two adjacent buildings and used for bearings of beams, chimneys, etc. for both buildings.

*Hollow walls* may be built provided the same amount of materials is used as is required for solid walls and they are properly bonded by proper ties.

*Parapet walls* are built over exterior and party walls above the roof and must be *coped*, or covered, with a flat stone or burnt-clay covering.



(a)



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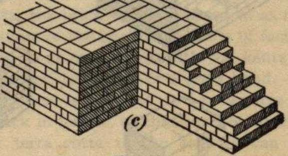


(c)

FIG. 1

## BOND

Brickwork lends itself to some very interesting and artistic effects, which are produced by various methods of *bonding*, or arranging the brick in the face of the wall; also by varying the size and colors of the mortar joints, and using bricks of different colors and textures. The following are some of the common terms used in connection with bonding:

A *course* is one horizontal row of brick laid in mortar.
A *stretcher* is a brick showing its long side in the face of the wall.
A *header* is a brick showing the end in the face of the wall.
A *bat* is a portion of a brick and is used sometimes as a header.

In Fig. 1 are shown the three principal bonds in brickwork. In (*a*) is shown English bond, consisting of alternate

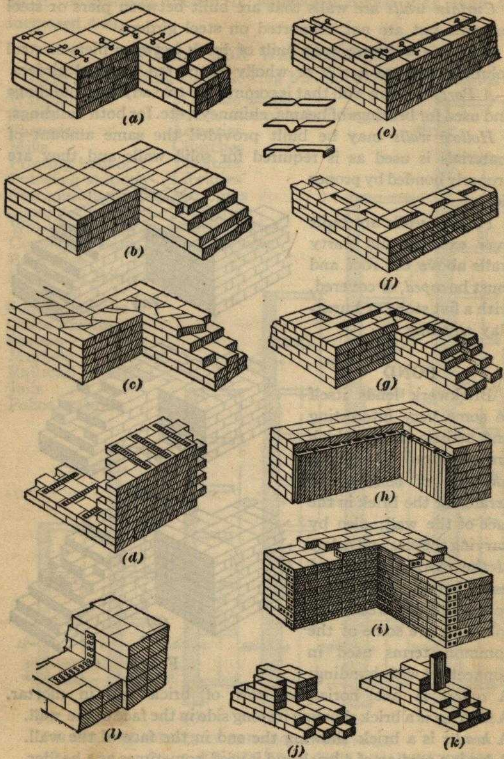



FIG. 2

courses of stretchers and headers. The longitudinal bond is obtained by means of one-quarter bats, as shown, though preferably by three-quarter bats. In (*b*) is shown Flemish bond, consisting of alternate headers and stretchers in the same course. The lap is obtained by use of three-quarter bats, with quarter, half, and three-quarter interior closers. In (*c*) is shown the ordinary bond known sometimes as *garden* or *running* or *American bond*. It consists of five or six courses of stretchers to each course of headers.

From (*a*) to (*g*), Fig. 2 are shown methods of bonding face brick to the backing in both solid and hollow walls; also of bonding terra-cotta furring to walls. In (*h*) is shown terra-cotta furring, which is set in mortar against the brick walls and anchored to the walls by large nails. In (*i*), the brick wall is lined with hollow brick, which are bonded into the wall and take the place of furring and lathing. In (*j*), (*k*), and (*l*) are shown methods of joining old and new walls; (*j*) shows a vertical groove cut in the old wall to form a sliding joint with the new wall; (*k*), a $2'' \times 4''$ piece spiked to the old wall for the same purpose; and (*l*), a steel-tie bond fastened to the walls with nails (also adapted for bonding face brick).

## LAYING BRICK WORK

Where the wall is built entirely of common brick, the joints are from $\frac{1}{4}$ in. to $\frac{3}{8}$ in. thick. When the wall is faced with face brick, stone, or terra cotta, the brick wall is referred to as the *backing*. The distance apart of the horizontal joints of facing material must be designed so as to coincide with the joints of the backing every few courses, to permit of a good bond. A face-stone or terra-cotta course is designed to be, say five or six courses of common brick in height, so that the iron anchor that holds the stone or terra cotta to the backing can be extended back into the wall. When face brick is used and the distance from center to center of joint is different from that of the backing, the joints should be made to coincide every five or six courses so as to permit of good bonding.

In laying up a wall, skilled workmen are put on the corners of the building and start the wall plumb and with the proper bond and thickness of joint. A line is then stretched between

these corners for every course and the intermediate wall is laid up to the line. The face brick is sometimes carried up to the next bond course before the backing is laid. Sometimes one gang of masons will lay up the face work, while another gang will build the backing at the same time.

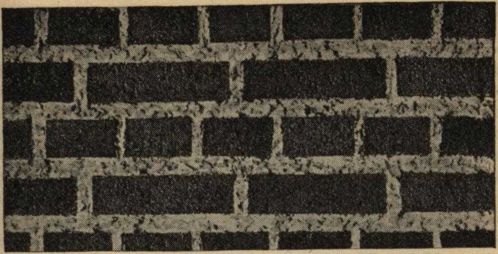
Bricks should be laid in a full bed of mortar and shoved into place so that the mortar will fill all the joints. The spaces in the middle of the wall should be entirely filled with mortar. When the weather is hot, the bricks should be thoroughly wet before they are laid in the wall so that they will not absorb the water from the mortar. In freezing weather, the freezing point of the mortar may be lowered by adding salt or the materials may be warmed.

The walls should be covered over with boards or tarpaulins when the workmen are through for the day to protect them from rain and cold weather, and to prevent injury by frost.

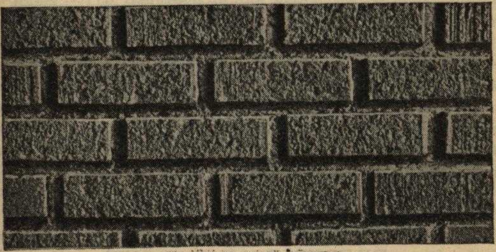
**Face Brick.**—In addition to its other valuable qualities, brickwork has great artistic possibilities. Face bricks are made in a great variety of colors, surface textures, and, when laid up in various bonds with mortar joints of different widths and colors produce wall surfaces that are very artistic. The textures vary from the perfectly smooth uniform surface of the pressed brick shown in the repressed brick in Fig 1 to the extremely rough surface in the Greendale Rugs. By the use of various clays and shales and the admixture of chemicals an endless variety of color can be produced in making bricks.

The shapes of brick vary from the accurately pressed smooth faced brick to the rough and irregular shape. Bricks approximating the following sizes are known under the following names:

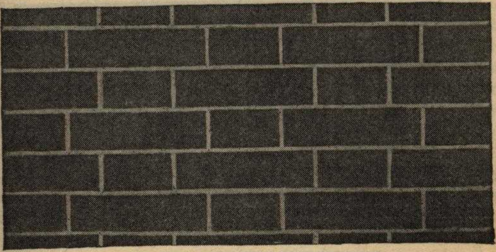
| Names of Sizes | Length | Width | Thickness |
|---|---|---|---|
| Roman, real............ | 17″ to 18″ | $5\frac{1}{2}$″ | $1\frac{1}{2}$″ |
| Roman................ | $11\frac{1}{2}$″ | 4″ | $1\frac{3}{4}$″ |
| Roman, short.......... | 8″ | 4″ | $1\frac{3}{4}$″ |
| Standard.............. | 8″ | 4″ | 2″ |
| Norman................ | $11\frac{5}{8}$″ | 4″ | $2\frac{1}{4}$″ |



BOKARA



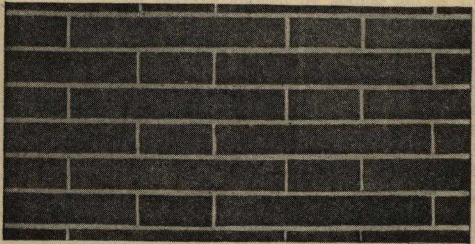
GREENDALE RUGS



RE-PRESSED-STANDARD SIZE

FIG. 1

IRON SPOTTED – STANDARD SIZE



RE-PRESSED – ROMAN SIZE

GREENDALE BRICK

FIG. 2

**Bond.**—A great variety of effects can be obtained by the judicious use of the various bonds in laying face brick, such as the English bond with Bokara brick; the Flemish bond in the repressed brick; the bond shown in the Greendale rugs brick, in Fig. 1, and the Dutch bond shown in iron-spotted brick, the Flemish bond with Roman size brick, and the modification of the Flemish bond with Greendale brick in Fig. 2. In the last example, the stretchers are formed of two single stretchers laid closely together so as almost to conceal the joint. The bond in face brick is no indication of the boı d used in the backing.

**Joints.**—The treatment of the joints can be made a very effective feature in face-brick work. The joints may be *raked out*, as shown in the Greendale brickwork in Figs. 1 and 2, and are often made as wide as 1 in.; or they may be made of mortar containing gravel or grit, and made wide and cut off flush with the face of the wall, as in the Bokara brick-work; they may be made fine and finished with great care as in the repressed-brick samples. In the iron-spotted brick sample the vertical joints form a diagonal pattern over the wall.

**Mortar.**—For thick rough joints, the mortar should be mixed with grit or small pebbles and a small quantity of hydrated lime. If a white color is desired, white cement with white sand or marble dust should be used in making the mortar. A gray color is obtained by using dark-colored Portland cement and brown sand. Mortar may be colored by using mineral pigments, but care must be taken to follow an exact formula in mixing the ingredients or the different batches of mortar may be differently colored, and cause the wall to look blotchy. When mortar dries out it usually becomes lighter in color.

**Inserts.**—Odd-shaped brick, tiles, marble or brickwork in fancy patterns are often used with fine effect in connection with brickwork.

# CHIMNEYS AND FIREPLACES

## CHIMNEYS

In planning chimneys, the points to be considered are the height, and the number, size, and arrangement of the flues. Attention must also be given to the location in respect to valleys, etc. on the roof. To make the chimney draw properly, a separate flue should be provided, extending from each fireplace to the top of the chimney. For ordinary stoves and small furnaces, the flues may be 8 in.×8 in.; but if the furnace is large, it is better to make the flue 8 in.×12 in., and the same size should be used, when possible, for fireplaces having large grates. Flues are sometimes only 4 in. wide; but are then easily choked with soot and difficult to clean, so that a flue should not be less than 8 in. wide.

Flues should always be lined with some fireproof material; in fact, the building laws of large cities so require. The lining is usually fireclay, tile, or galvanized-iron pipe. If the pipe used is round, the space between it and the walls of the chimneys may be utilized for ventilation.

Where flue linings of fireclay or terra cotta are used the outer walls of the chimney are usually made 4 in. thick. The walls should be made 8 in. thick if no flue linings are used and the flues should be carefully pointed up and not plastered. The brick partitions between flues are called *withes*.

Whenever it is necessary to change the direction of the flue, the diversion should be effected by easy bends, and not by sharp turns, which retard the passage of smoke. Chimneys should extend above the highest point of the building or of those adjoining; otherwise they are likely to smoke. This fault may be remedied, when the chimney is not carried high enough, by using a hood having two open sides; but as hoods are unsightly, their use should be avoided, when possible.

In the accompanying table are given dimensions of rectangular and round flues also their effective areas.

For fireplaces, in which it is intended to burn anthracite coal, the flue should have an area equal to one-twelfth or one-fifteenth of the area of the fireplace opening. Where wood or

bituminous coal is to be used, the flue area should be one-tenth or one-twelfth of the area of the fireplace. Thus, for a fireplace 36 in. wide and 30 in. high designed for burning wood, the flue lining should be from one-tenth to one-twelfth of 36×30, or 1,080 sq. in., or from 108 sq. in. to 90 sq. in. From the accompanying table it is found that an $8\frac{1}{2}''\times 18''$ flue has an interior area of 104 sq. in. and that a 12 in. round flue has an area of 113.10 sq. in. Either of these flues may be used. If anthracite coal is to be burned, the smallest flue should be

**DIMENSIONS AND EFFECTIVE AREAS OF FLUES**

| Rectangular Flue | | Round Flue | |
|---|---|---|---|
| Outside Size Inches | Approximate Inside Area Square Inches | Inside Diameter Inches | Inside Area Square Inches |
| $4\frac{1}{2}\times 8\frac{1}{2}$ | 16.25 | 6 | 28.27 |
| $4\frac{1}{2}\times 13$ | 27.50 | 7 | 38.48 |
| $4\frac{1}{2}\times 18$ | 40.00 | 8 | 50.27 |
| $8\frac{1}{2}\times 8\frac{1}{2}$ | 42.25 | 9 | 63.62 |
| $8\frac{1}{2}\times 13$ | 71.50 | 10 | 78.54 |
| $8\frac{1}{2}\times 18$ | 104.00 | 12 | 113.10 |
| 13 ×13 | 121.00 | 15 | 176.72 |
| 13 ×18 | 176.00 | 18 | 254.47 |
| 18 ×18 | 256.00 | 20 | 314.16 |
| | | 24 | 452.39 |

one-fifteenth of 1,080 = 72 sq. in. From the table, it is found that an $8\frac{1}{2}''\times 13''$ rectangular or a 10-in. round flue will suffice.

The part of the chimney projecting above the roof should be laid up with strong cement mortar so as to prevent disintegration and should be covered with a protecting cap of stone or cement. This cap may be pierced with holes to match the flues as shown in Fig. 1 where *a* is the capstone of the chimney with holes *b* cut through flush with the inner edge of the flue lining and covering the joints between the brickwork and the linings. A chimney cap that is not perforated is shown at *a*,

Fig. 2. This cap is supported at the four corners by small brick piers between which the smoke passes through the

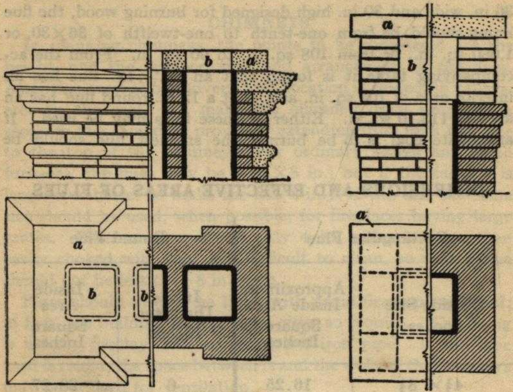



FIG. 1 FIG. 2

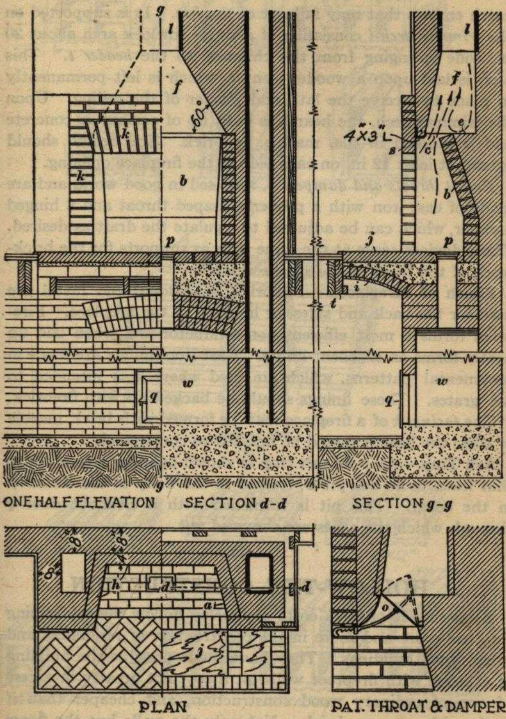
spaces *b*. This cap prevents rain from falling directly into the chimney.

## FIREPLACES

The general construction of a fireplace in a dwelling is shown in the accompanying illustration. The projection of the chimney into the room is called the *chimney breast*. The height of a fireplace should be about 2 ft. 6 in. to 2 ft. 8 in. above the finished floor, its depth from 16 in. to 24 in. and its width from 2 ft. to 5 ft. A properly designed fireplace should have sloping sides, as shown at *a*, with a slope of about 3 in. in 1 ft., so as to reflect the heat into the room.

The *back b*, should slope forwards and form the *throat c*, which should be from $2\frac{1}{2}$ in. to 4 in. in depth and of the same width as the fireplace opening. The total area of the throat should be not less than that of the flue lining. The throat should be at least 2 in. or 3 in. above the top of the opening of the fireplace as shown at *s*, and as near the front of the fireplace as possible.

The *smoke shelf e*, is an important feature. It prevents the air rushing down when the fire is started and forcing smoke into the room.




The *smoke chamber f*, is formed by drawing the brickwork together at an angle of 60° on the sides until it is reduced to the

dimensions of the flue lining. The *lining l*, is then started, being supported by the brickwork, as shown.

The *hearth j*, is extended in front of the fireplace so as to catch embers that may fall out of the fire. It is supported on the *trimmer arch i* consisting of a single rowlock arch about 20 in. wide springing from the chimney to the *header t*. This arch is laid upon a wooden center, which is left permanently in place to receive the lath and plaster of the ceiling. Upon the trimmer arch, the hearth is built up of cement or concrete and is finished in tile, marble, or brick. The hearth should extend at least 12 in. on each side of the fireplace opening.

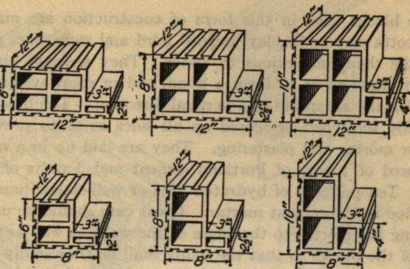
*Patent throats and dampers o*, are used in good work, and are made of cast iron with a properly shaped throat and a hinged damper, which can be adjusted to regulate the draft as desired. These devices serve at the same time as supports for the brickwork of the front of the smoke chamber.

**Finish of Fireplaces.**—Firebrick, soapstone, and metal are used for the back and sides, or lining *h*, of the fireplace. Firebrick forms a most efficient non-conductor and when laid up neatly forms an excellent lining. Cast-iron linings are made in ornamental patterns, which are used where it is intended to use grates. These linings should be backed up with firebrick. The *facings k* of a fireplace may be formed with brick, marble or tiles; the hearth should be finished to correspond.

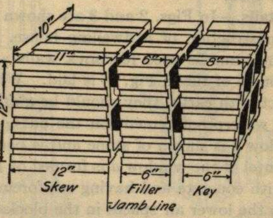
**Ash Trap.**—At *p* an ash trap is shown opening into a chute that leads to an ash-pit *w*, formed in the body of the chimney in the cellar. This pit is furnished with a cleanout door *q* through which the ashes are shoveled out.

## HOLLOW-TILE CONSTRUCTION

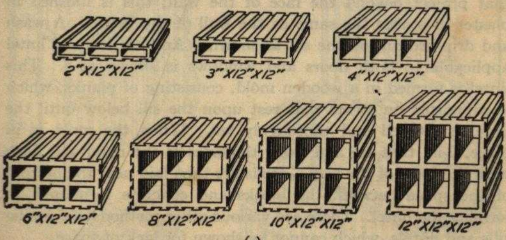
Blocks made of terra cotta or fireclay hollow tile are coming into use more and more in the construction of residences and other small buildings. They have made possible the building of a house with fireproof walls, at a cost not greatly in excess of one of ordinary wood construction, and cheaper than if made with common brick. Not only the walls but the floors and roof can be constructed of this material used in connection with concrete and steel reinforcement.


12"
6"
3"
2"
8"
2½"
10"
4"


(a)


10"
11"
6"
8"
12"
12"
Skew
6"
Filler
6"
Key
Jamb Line


(b)


2"X12"X12"
3"X12"X12"
4"X12"X12"
6"X12"X12"
8"X12"X12"
10"X12"X12"
12"X12"X12"


(c)

FIG. 1

The blocks used in this form of construction are made of terra-cotta clay or fireclay, burned hard and sometimes glazed to make them impervious to water. They are laid up with broken joints so as to form a bond, and in most systems are laid with the air spaces in a vertical direction. The blocks are generally scratched or scored on all sides so as to provide a key for mortar and plastering. They are laid up in a mortar composed of 1 part of Portland cement and 3 parts of clean sand. Ten per cent of hydrated lime or well-slaked lime may be added to the cement mortar. Great care should be used in applying the mortar to the edges of the webs as well as to the sides of the blocks so that the joints shall be thoroughly filled.

In Fig. 1 (*a*), (*b*), and (*c*) are shown some of the forms of blocks that are used.

**Building Details.**—In Figs. 2 and 3 are shown various details used in the construction of a dwelling house. The concrete footings are the same as used for brick walls and upon them the starting course of tile *b*, Fig. 2, is laid. Where the blocks come in contact with earth, they should be glazed or receive a heavy coat of waterproof cement on the outside. The sill of the cellar window *c* is shown of stone and is backed up by the tiles *t*. The lintel of the window *d* is formed of 12″×12″×12″ blocks filled with concrete and having reinforcing rods of steel put in through the lower air spaces in the blocks.

Another window sill *e* is formed of tiles, 2 in. or 3 in. thick, that project beyond the face of the wall; this is finished in plaster or stucco the same as the wall of the house. A wash and drip are run on the sill as shown. Another form of lintel applicable to both doors and windows is shown at *f*. This lintel is formed in a wooden mold, consisting of planks, which is supported on struts that rest upon the sill below until the lintel is formed and thoroughly set. When the mold is in place, 2-in. tiles are laid along the sides of the mold and flush with the faces of the wall. Rods are then laid near the bottom of the space between the blocks and concrete is poured in, forming the lintel. There are various other methods of forming sills and lintels, which cannot be shown for lack of space.

**Floor Construction.**—A fireproof floor, in which joists of reinforced concrete are used and which shows the use of tile,

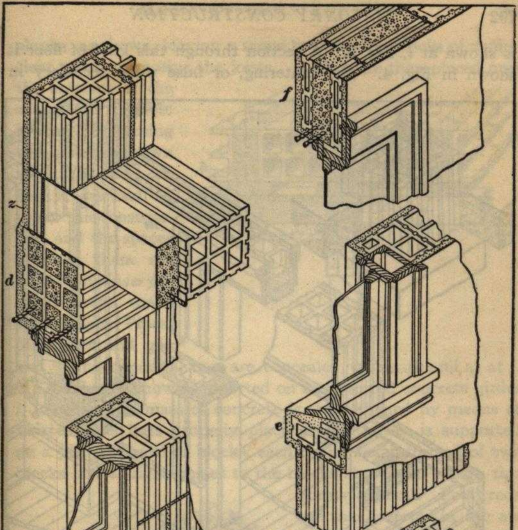



FIG. 2

is shown at *i*, Fig. 3. A section through this kind of floor is shown in Fig. 4. The centering, or false work necessary in

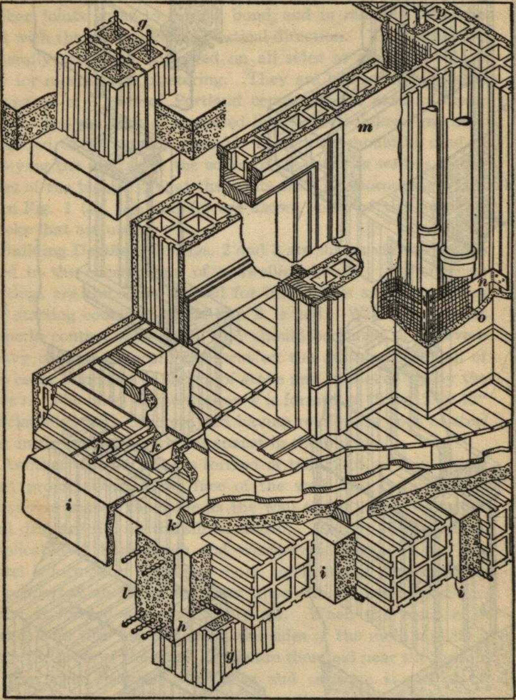



FIG. 3

constructing this floor, consists of planks laid 16 in. on centers. The blocks are set with the edges resting on these

planks, as shown, leaving a space between the blocks of sufficicient width to receive the joists. Rods *b* are then placed near the bottoms of the spaces and concrete is poured in forming the joists, as shown at *c*. Sleepers *k*, Fig. 3, are laid on top of this construction and the spaces between them are filled with *cinder fill*, or concrete made with cinders. Pipes, for water and gas and wiring conduits, etc. are concealed within the fill as at *j*.

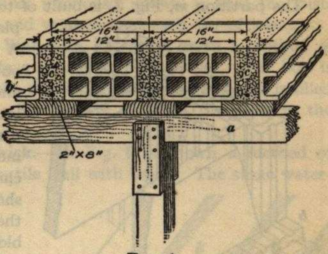


FIG. 4

This floor is shown supported on a reinforced concrete girder *l*, in which the mass of concrete is strengthened by means of twisted steel bars properly placed. The girder is supported on a pier *g* formed of blocks, each course being formed of two blocks laid at right angles to the blocks above and below; this forms a bond. Four rods are then inserted in the air spaces in the blocks and the whole pier is filled with concrete. The footing for this pier is shown at the top of the figure.

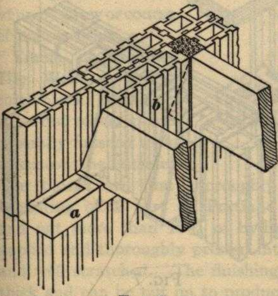


FIG. 5

Another form of floor construction in which tile is used is shown at *q*, Fig. 2. This type is known as the *Johnson system floor* and consists of a 1-in. layer of cement, reinforced with rods and metal fabric or mesh, upon which hollow tile are laid, the joints being filled with mortar. This construction is shown resting on a 1-in. tile slab *r*, which covers the air

spaces of the wall blocks and provides a good bearing for the floor.

The partition *m*, Fig. 3, is built of terra-cotta blocks and is plastered on both sides. A pipe chase is furred out with metal furring *n* and enclosed with metal lath *o*, upon which the plastering is applied. A method of making a pipe chase in the outer walls is shown at *p*. In this case, the inside webs of the blocks are broken away and the pipes inserted after which the opening is covered with wire lath and plastered.

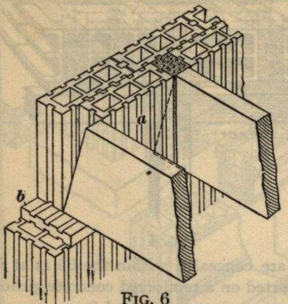


FIG. 6

**Supporting Wooden Floor Joists.**—In Fig. 5, is shown a method of resting floor joists on terra-cotta walls. The joists are spaced 16 in. on centers, which allows the placing of a 12-in. block *b* between the ends of each pair of joists. A row of brick stretchers *a* is often used to support the ends of the joists, when the depth of the joists is less than the height of the blocks.

Instead of a course of bricks being used, to support the joists, a course of 1-in. tile which covers the entire thickness of the wall, as shown at *b*, Fig. 6, is often used. In each of these methods the space between the ends of the joists and the wall is generally filled with concrete

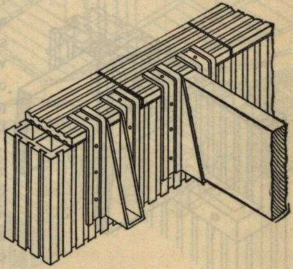


FIG. 7

In Fig. 7 is shown a third way of supporting wooden floor joists; in this case joist hangers are used. This method has the advantage over those previously shown, in that the joists do not enter the wall and weaken it at each tier of joists.

**Fastening Roof to Wall.**—In Fig. 8, is given a method of bolting down the plate *a* to the top of the wall. The bolt is held in position and the air cell in which the bolt sets is filled with cement mortar. The rafters *b* set on the plate in the regular manner.

**Veneering With Brick.**—In Fig. 9 is shown a method of veneering a terra-cotta tile wall with brick. The stone water-table *a* rests on the thicker blocks of the cellar wall and upon it the brickwork is built in front of the terra cotta. At every tenth or eleventh course of brickwork, the brick veneer is tied to the tile backing as at *b*. This bonding course is backed up by a row or course of hollow brick, *c*.

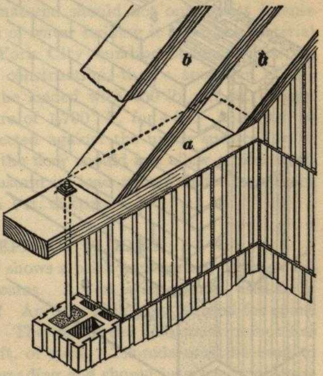


FIG. 8

**Finish of Hollow-Tile Walls.** — Terra-cotta-block buildings, when not veneered, are generally finished with stucco on the outside. The blocks are first thoroughly wet and a scratch coat, consisting of 1 part of Portland cement, 3 parts of sand, and not more than 10% of hydrated lime or lime putty, is applied and thoroughly pressed into the grooves in the blocks, and well scratched. The finishing coat should be about ¼ in. thick and can be put on to produce different effects of texture and color. By using a white cement and marble screenings, a white marble-like effect is obtained; by using gray cement and brown sand, a warm gray color is obtained.

The cement may be dashed on, or thrown on with a trowel and a rough texture obtained, or the surface may be troweled and made comparatively smooth. Colored pebbles, marble chips, etc. may be pressed into the surface and, when the stucco is dry, washed down with dilute muriatic acid and a brush. The colors of the stones and chips will then appear and give a tint to the entire surface. For examples of this kind of work see Figs. on pages 224 and 225.

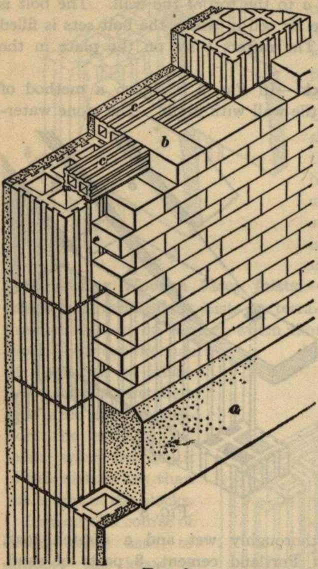


FIG. 9

**Dampness in Hollow-Tile Construction.** While it is claimed that a wall formed of hollow tile is waterproof and heat-proof, there is always danger, in cold weather, of moisture forming on the surface of the plaster if the plaster is applied directly to the inner surface of the wall. This is due to the fact that the low temperature is conveyed through the shells and webs of the blocks and the plaster is cooled, and moisture from the air of the room is condensed upon its surface. A safe precaution is to place furring strips against all outside walls to receive the plastering, as is done with brick walls, thus providing a continuous air space through which moisture, heat, and cold cannot pass.

# FIREPROOFING

## GENERAL REMARKS

The fireproofing of buildings is accomplished either by enclosing a framework of steel, which in itself will soften and bend under the influence of great heat, with an incombustible material such as brick, terra cotta, or concrete; or by forming the entire structure of a fireproof material, which will also supply sufficient strength for the various parts of the structure, such as concrete or terra cotta.

A good fireproofing material should not only resist intense heat but also the effects of water striking it when the material is heated. The New York City building code provides, in tests for fireproof floor construction, that a specimen of the floor to be tested shall be loaded with 150 lb. per sq. ft. and exposed to a temperature of 1,700° F. for 4 hr. A stream of water shall then be directed against the under surface for 10 min. To pass the test the floor should not allow smoke to go through it, and must sustain its load with a deflection of not more than $\frac{1}{8}$ in. for each 1 ft. of span.

## FIREPROOF FLOORS

**Brick Arches.**—Fig. 1 shows a brick arch sprung between the lower flanges of the **I** beams. A 4-in. arch may be used for a span not exceeding 5 ft. An 8-in. arch may be used for spans between 5 ft. and 8 ft. The rise of the arch must be not less than $1\frac{3}{4}$ in. for each 1 ft. of span. Tie-rods must be used to keep the beams from spreading and should be spaced not more than eight times the depth of the beam apart.

The left half of Fig. 1, shows a single rowlock arch with a filling of concrete over it extending slightly above the level of the top of the beam. It also has a plastered ceiling on the soffit of the arch and around the bottom flange of the **I** beam, which is wrapped with metal lath to receive it. On the right hand side is a double rowlock, or 8-in. arch with a flat ceiling hung from the lower flanges of the **I** beams on metal lathing.

**Side-Construction, Terra-Cotta Arch.**—Fig. 2 illustrates a side-construction terra-cotta arch, in which the air spaces in

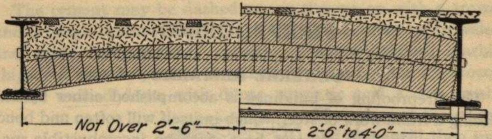



FIG. 1

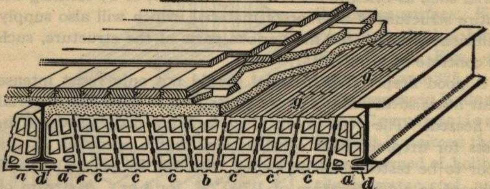



FIG. 2

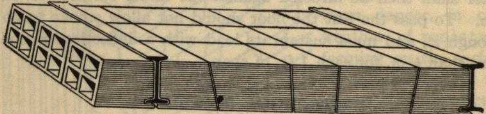


FIG. 4

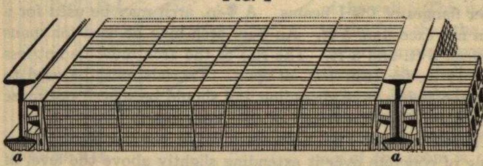



FIG. 5

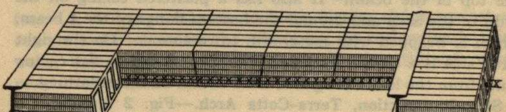


FIG. 7

the blocks run parallel with the beams. At *a* are shown the *skewbacks*, which fit snugly against the beams and cover the lower flanges of the beams with the protection lips *d*. Another form of flange protection is shown in Fig. 5, which consists of a *soffit tile a* held in place by the skewbacks.

At *b*, Fig. 2, is shown the *key*, and at *c* the lengtheners. The blocks in this system are laid with joints broken, as at *g*. The space between the top of the arch and the tops of the beams is filled with a concrete filling made of 1 part of Portland cement and 10 parts of sand, cinders, and broken tile. This space is sometimes filled with hollow tile *fillers e*, Fig. 8. Upon the concrete filling, the sleepers are laid at right angles to the beams and are generally secured to the I beams by means of steel clips, as shown at *a*, Fig. 3. The space between the sleepers is filled with concrete to within ½ in. of their upper surface. Tie-rods should always be used with terra-cotta arches to take up the thrust of the arches. The plastering can be applied directly to the under surface of the arch in the systems shown in Figs. 1, 2, 4, 5, 7, and 8, to form the ceiling.

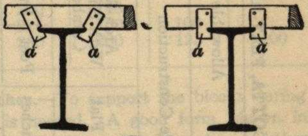


FIG. 3

**End-Construction Terra-Cotta Arch.**—An end-construction terra-cotta arch is shown in Fig. 4, in which the air spaces in the blocks run perpendicular to the beams. The webs as well as the outer shell of the blocks convey the floor load to the beams. On account of the greater strength of this system, it has to a great extent superseded the side construction method shown in Fig. 2.

**Combination Arch.**—A combination arch, formed of the end-construction arch with side-construction skewbacks, is shown in Fig. 5. This skewback affords a better protection for the beam. The blocks cannot be laid with broken joints in this system and each arch is complete in itself.

The table on page 200 gives the weight per square foot and the allowable span between beams of terra cotta of various depths. The heavier weights are the ones commonly used.

## WEIGHT OF SEMI-POROUS, TERRA-COTTA, FLAT-ARCH, FLOOR CONSTRUCTION

| Depth of Arch | Weight Pounds per Square Foot | | Allowable Span Between Beams | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Side Construction | | | | End Construction | | | |
| | | | Arch Set Flat | | Arch Set With Slight Camber | | Arch Set Flat | | Arch Set With Slight Camber | |
| Inches | Side Construction | End Construction | Feet | Inches | Feet | Inches | Feet | Inches | Feet | Inches |
| 6 | 24 to 26 | 20 to 25 | 4 | 0 | 4 | 6 | 4 | 6 | 5 | 0 |
| 7 | 26 to 28 | 22 to 26 | 4 | 6 | 5 | 6 | 5 | 0 | 5 | 9 |
| 8 | 27 to 32 | 24 to 30 | 5 | 0 | 6 | 0 | 5 | 6 | 6 | 6 |
| 9 | 29 to 36 | 26 to 34 | 5 | 6 | 7 | 0 | 6 | 0 | 7 | 0 |
| 10 | 33 to 38 | 28 to 36 | 6 | 6 | 7 | 6 | 6 | 6 | 7 | 6 |
| 12 | 37 to 44 | 30 to 40 | 7 | 0 | 8 | 6 | 7 | 6 | 9 | 0 |
| 15 | | 37 to 50 | | | | | 9 | 0 | 10 | 0 |

The lighter weights can be made if required. The following table gives the approximate safe load on flat tile arches.

**APPROXIMATE SAFE LOAD ON FLAT-TILE ARCHES**

| Depth of Arch Inches | Distance Between Beams | | | | |
|---|---|---|---|---|---|
| | 4 Ft. | 5 Ft. | 6 Ft. | 7 Ft. | 8 Ft. |
| | Safe Load, in Pounds per Square Foot | | | | |
| 6 | 150 | 100 | | | |
| 7 | 200 | 150 | | | |
| 8 | 275 | 175 | 125 | | |
| 9 | 300 | 200 | 140 | | |
| 10 | 325 | 225 | 150 | 100 | |
| 12 | 400 | 250 | 200 | 125 | 100 |

**Centering for Flat Arches.**—To support the blocks during laying, a firm *centering* is needed. A good form, shown in Fig. 6, is made of 1-in. boards *a*, dressed and set close together and resting on a 4″×4″ or 4″×6″ piece *b* that extends parallel with the beams and midway between them. The piece *b* is

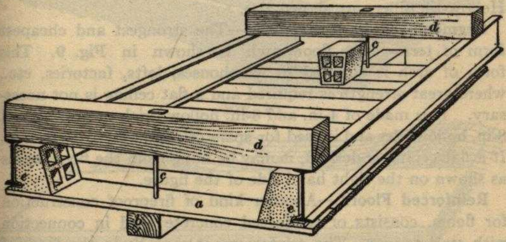



FIG. 6

suspended by T-headed bolts *c* from similar pieces *d*, which are laid across the top of the beams. The tiles forming the

**I**-beam protection are put in place first and, if they are separate pieces, are laid on the planks directly beneath the beams; or, if the **I** beams are protected by the skewbacks, as at *e*, the latter are set first. The bolts are then tightened so as to bend the planks slightly, forming the camber, which crowning should be ¼ inch for a 6-foot span.

In setting the blocks, the pieces should be adjusted so that the surfaces will abut properly. Only the best cement mortar should be used, and the joints should be made thin, but care should be taken that the mortar does not become pressed out. The centering should be kept in place until the mortar between the blocks has set, which takes from 12 to 36 hrs. When the centering is removed, the arch should have a level surface, showing no open joints or projecting blocks. If holes in the floor are required, they may be punched in the blocks and closed afterwards with broken tile and mortar; or, if the side-method arch is laid, a block may be temporarily omitted.

**New York Arch.**—In Fig. 7 is shown a flat-end construction arch known as the New York arch, which is reinforced by the addition of a woven wire strip embedded in the mortar between the arches.

**Excelsior Terra-Cotta Arch.**—Fig. 8 shows the Excelsior terra-cotta arch, in which the blocks have special shapes. Hollow-tile fillers are shown at *e*.

**Segmental Terra-Cotta Arch.**—The strongest and cheapest form of terra-cotta floor arch is shown in Fig. 9. This form of arch is adapted to warehouses, lofts, factories, etc., where great strength is required and a flat ceiling is not necessary. It is made of 4-in. and 8-in. hollow brick or of 6-in. and 8-in. hollow tiles and is used for spans of from 4 ft. to 10 ft. 6 in. If a flat ceiling is desired, it may be hung from the floor beams as shown on the right hand side of the figure.

**Reinforced Floors.**—Another kind of fireproof construction for floors, consists of reinforced concrete used in connection with steel beams. The reinforcement may be in the form of wire cables, square or diagonal wire mesh, rods, bars, steel plates, or unit trusses. These floors are built on wooden forms which are left in place until the concrete has set.

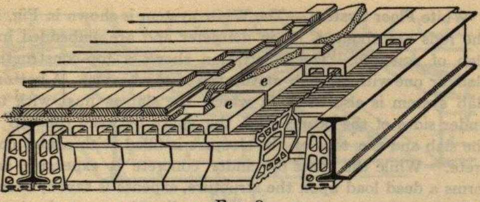



FIG. 8

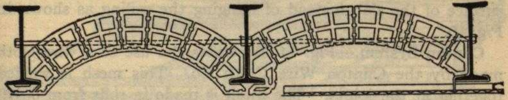


FIG. 9

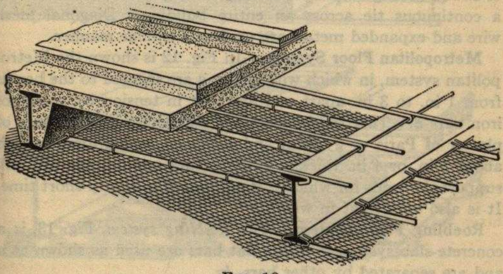


FIG. 10

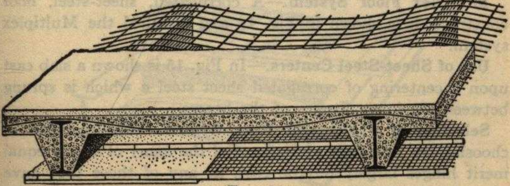


FIG. 11

**White Floor System.**—The White system is shown in Fig. 10, the rods are about $\frac{9}{16}$ in. in diameter and are embedded in a slab of concrete. The illustration shows a top-construction slab, or one with the slab at the top of the beams. A bottom-slab system is also used, in which the slab is flush with the under sides of the beams and the space between the top of the slab and the tops of the sleepers is filled with cinder concrete. While the mass of cinder concrete is expensive and forms a dead load upon the structure, expense is saved, when a flat ceiling is desired, by plastering directly upon the lower surface of the slab instead of hanging the ceiling as shown in Fig. 10.

**Clinton System.**—Fig. 11 illustrates the use of a wire cloth made by the Clinton Wire Cloth Co. This mesh is welded together at the joints. The mesh is made in rolls from 60 ft. to 300 ft. in length thus permitting of long spans and of forming a continuous tie across an entire building. Diagonal mesh wire and expanded metals are used in a similar manner.

**Metropolitan Floor System.**—In Fig. 12 is shown the Metropolitan system, in which wire cables *a* are secured to the beams from 1 in. to 3 in. apart and are kept in tension by means of iron bars *d*. This reinforcement is embedded in a mixture of plaster of Paris or gypsum and shavings, which forms a slab about 3 in. or 4 in. thick. This mixture sets quickly and will support the loads for which it is calculated in a very short time. It is also very light in weight.

**Roebling Floor System.**—The *Roebling system*, Fig. 13, is a concrete-slab system in which flat bars are used as shown at *a* and are separated by other bars, *b*.

**Multiplex Floor System.**—A corrugated, sheet-steel, floor construction is shown in Fig. 14 and is called the Multiplex system.

**Use of Sheet-Steel Centers.**—In Fig. 15 is shown a slab cast upon a centering of corrugated sheet steel *a* which is sprung between the lower flanges of the beams.

**Selection of a Fireproof Floor System.**—The question of choosing the best floor system out of the many of nearly equal merit hinges largely on the cost, as any of those that have been described will be found amply strong and, as a rule,

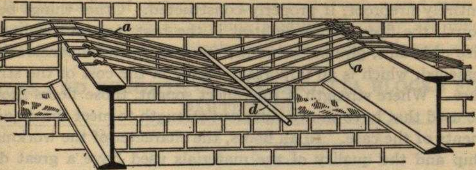



FIG. 12

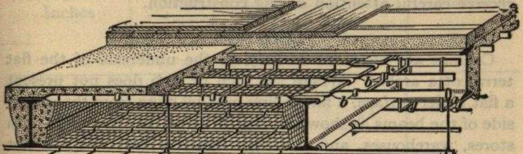



FIG. 13

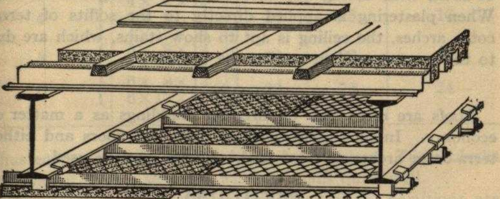


FIG. 14

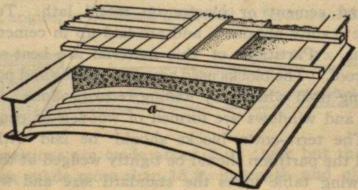



FIG. 15

entirely fireproof, if properly constructed. Other things being equal, the floor that is lightest is the best, as the weight and size of beams, girders, columns, etc. may then be considerably lessened, which is an important factor in the cost of the structure. Where strength is the object sought, those floors should be used that have shown sufficient strength to meet the requirements of the case. In all floors, the character of the workmanship and the quality of the materials used have a great deal to do with the durability and efficiency, and hence should receive careful attention during construction.

## CEILINGS

Ceilings are plastered directly on the underside of the flat terra-cotta arches. Where the arch or slab does not present a flat under surface, a flat ceiling may be hung from the underside of the beams as shown in Figs. 1, 9, 10, 11, 13 and 14. In stores, warehouses, and buildings where a flat ceiling is not necessary, the plastering may be applied directly to the slab or arch, thus saving the cost of metal furring and lathing. When plastering is applied directly to the soffits of terra-cotta arches, the ceiling is apt to show stains, which are due to the mortar used in setting the blocks.

## ROOFS

Roofs are often flat on fireproof buildings as a matter of economy. In such cases they are built like floors and either terra-cotta arches or reinforced concrete may be used.

## PARTITIONS

Fireproof partitions are made of terra-cotta or gypsum blocks, and cement or plaster on metal lath. Terra-cotta blocks are readily obtained, and are laid up in cement mortar by masons. Partitions of this material are heat-sound-and vermin-proof. The blocks used are semi-porous and porous, the latter being used where any nailing is to be done. Openings for doors and windows are formed of wooden or channel iron bucks. The terra-cotta blocks should be laid with broken joints and the partition should be tightly wedged at the ceiling. The following table gives the standard size and weights of blocks up to 6 in. thick, and safe heights of partition.

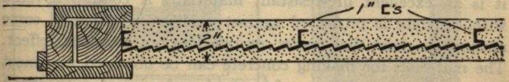
Blocks made of gypsum or plaster of Paris mixed with a tough fibre are used in building partitions. They are much lighter than terra-cotta blocks and are made in larger sizes,

**SIZES AND WEIGHTS OF TERRA-COTTA BLOCKS FOR PARTITIONS**

| Thickness Inches | Standard Size Inches | Weight per Square Foot Pounds | | Safe Height of Partition |
|---|---|---|---|---|
| | | Semi Porous | Porous | Feet |
| 2 | 2×6×12<br>2×8×12<br>2×12×12 | 12 | 14 | |
| 3 | 3×6×12<br>3×8×12<br>3×12×12 | 14 | 17 | 12 |
| 4 | 4×6×12<br>4×8×12<br>4×12×12 | 16 | 18 | 16 |
| 5 | 5×8×12<br>5×12×12 | 19 | 22 | 20 |
| 6 | 6×8×12<br>6×12×12 | 22 | 26 | 24 |

thus economizing in weight, labor and mortar. These blocks can be cut with a saw and will hold nails quite well.

As shown in the accompanying illustration, partitions are made of metal lath stretched upon a frame-work of light channels, angles, or bars and plastered to form a solid partition.




These partitions are made about 2 in. thick but they are not rigid when made more than 15 ft. in length and about 12 ft. in height.

Partitions on metal lath that are thicker than 2 in. are generally made with a covering of lath on each side of the metal studding and plastered both sides.

## COLUMNS AND GIRDERS

**Columns.**—Columns should be protected with not less than 2 in. of fire-proofing material. For a plain round, cast-iron column, segmental blocks of terra cotta are sometimes used. As shown in Fig. 1, these blocks *a* are made with lugs on the inner side which rest against the column. They are set with the joints broken and are tied together by metal binders *b*.

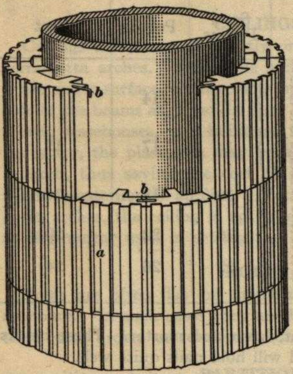


FIG. 1

In Fig. 2 (*a*), (*b*), and (*c*) are shown methods used to fireproof columns of different shapes with terra-cotta blocks. These blocks are set breaking joints and are tied with copper wire at intervals of 1 ft. or so. Where pipes are run up beside the columns, they should be placed as shown at *a*, view (*c*) so that it will not be necessary to destroy the fireproof shell of the column if it becomes necessary to get at the pipes,

Concrete is a valuable material for fireproofing columns, as it is an excellent fire-resistant material. A column covered with concrete is protected against oxidization although some authorities claim that *cinder concrete* does not have that effect. The materials for making concrete can be obtained in almost any locality and they can be mixed and applied with cheap labor. A mold *c*, Fig. 2 (*d*), is bolted around the column and concrete is poured into the space between it and the column as shown. After the concrete has set for a few days, the mold

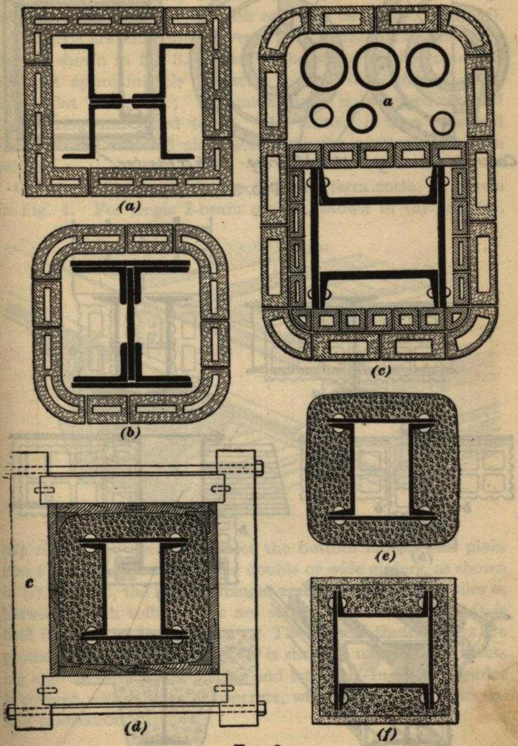



FIG. 2

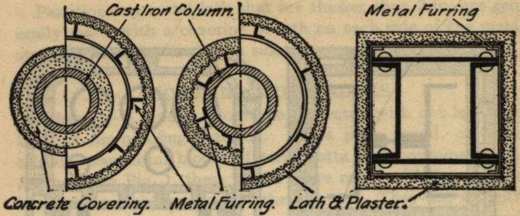

Cast Iron Column.
Metal Furring
Concrete Covering.
Metal Furring.
Lath & Plaster.

FIG. 3

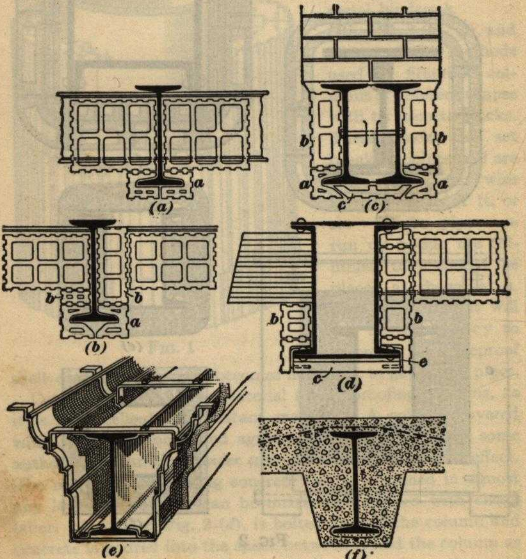
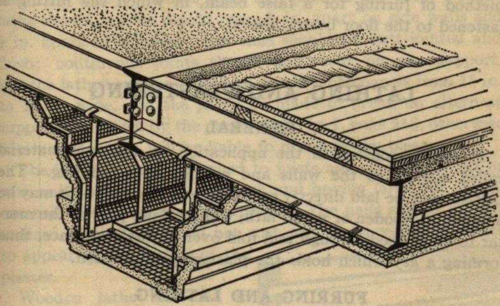

a
(a)
b
b
a
a
c
(c)
b
b
a
(b)
b
b
e
c
(d)
(e)
(f)

FIG. 4

may be removed leaving the completed column as shown in (*e*), and the mold may be used elsewhere. Upon the rough concrete surface, a plaster finish can then be applied, as in (*f*).

Columns are sometimes covered with metal furring and lathing, as shown in Fig 3. The finished shape of the column is laid out approximately in metal furring, consisting of angle irons, flat bars, etc.; the metal lath is wrapped around the furring and wired to it. The lathing is then plastered and with the enclosed air space forms the protection for the column.

**Girders.**—Girders are fireproofed with terra cotta, as shown in Fig. 4. For single **I**-beam girders, shown in (*a*) and (*b*),



*clip tiles a*, are used to protect the bottom flanges and plain tiles *b* to cover the sides. For double or wide girders, as shown in (*c*), and (*d*), the bottom flanges are covered with clip tiles *a*, between which soffit tiles *c* are set. The soffit tile in (*d*) is held in place by iron clamps *e*. The sides of these girders are protected by plain tile *b*. In (*e*) is shown a method of protecting a girder with metal furring and lathing. In (*f*), the girder is covered with a mass of concrete, which protects it from fire and oxidization.

## METAL FURRING AND LATHING

Where elaborate architectural features, such as vaulted surfaces, cornices, beams, ceilings, etc. are desired, they are often formed of a construction of light angles and bars called metal furring secured to the frame of the building and covered with wire lath and plastered. The metal furrings should be designed to support these features as well as to brace them so that they will be rigid. The furrings should be spaced so as to take wire lath of stock widths. The metal lath is stretched upon the furring and fastened to it by means of No. 18, galvanized, lacing wire. The figure on page 211 illustrates the method of furring for a false beam, in which the furring is fastened to the floor beams above.

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## LATHING AND PLASTERING

### GENERAL

*Plastering* consists in the application of a plastic material called *mortar*, to the walls and ceilings of a building. The plaster may be laid directly on the face of the wall, or it may be applied on wooden or metal lath, which allows part of the mortar to be pressed through and fold over on the inner face, thus forming a *key* which holds the plastering in position.

### FURRING AND LATHING

On brick or stone walls, lathing is usually attached to vertical furring strips, 1 in. thick by 2 in. wide, set 12 in. or 16 in. on centers. By this means, there is a clear air space between the plaster and the wall, thus insuring a continually dry plaster surface. In the case of frame buildings, the lath is attached directly to the studs forming the framing of the walls and partitions. The ceiling lath may be nailed directly to the under edges of the joists, or attached to cross-furring, which consists of $1'' \times 2''$ strips of wood, set at right angles to the joists and fixed at 12-in. on centers. Wooden laths may be either split or sawed; the former gives a better wall, as there are no cross-grained fibers to reduce the strength, while in the latter

such fibers make the lath curl and warp by absorbing moisture from the mortar; being cheaper, however, sawed lath is generally used.

Lath made of pine, spruce, or hemlock, should be straight-grained, well-seasoned, free from sap and rot, clear of shakes and large or loose knots, and, to prevent the subsequent discoloration of the plaster, should be free from live knots and resinous pockets. The regular size of a lath strip is $\frac{1}{4}$ in.$\times 1\frac{1}{2}$ in.$\times$4 ft., the length regulating the spacing of the furring strips, studs, and joists.

Lath is nailed in place in parallel rows, the edges being kept a full $\frac{1}{4}$ in. apart, to enable the soft plaster to be pressed through and form a key. Where hard wall plasters are used, wooden laths should not be placed over $\frac{3}{16}$ in. apart on side walls and $\frac{1}{4}$ in. apart on ceilings. The ends should be butt-jointed and flush; continuous joints should not occur on one support, but the lathed surface should be divided into panels from 15 in. to 18 in. wide, and the joints be made to break on alternate supports, as shown by the panel *abcd*, Fig. 1, page 218, otherwise continuous cracks will be liable to disfigure the plaster.

The lath is usually attached to joists and studs with cut or wire nails, about $1\frac{1}{8}$ in. in length and having large flat heads, one nail being used at each support. The nails should be galvanized, so that they will not rust, and cause yellow blotches to appear on the surface of the plaster.

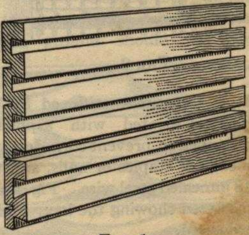


FIG. 1

Wooden laths are sold in bundles of 100; 1,000 laths will cover about 570 sq. ft. of surface and will require about 5 lb. of 3-penny fine nails.

**Sheathing Lath.**—A combination sheathing and lath for exterior use, the *Byrkit lath*, shown in Fig. 1, is very useful for exterior plastering, the dovetail channels affording an excellent key for the plaster.

*Plaster board* is a composition of alternate layers of strong, fibrous felt and gypsum plaster, made in sheets 32 in.$\times$36 in.

Its thickness varies from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. This board can be cut with a saw and is used to take the place of the lath and the scratch coat of plaster, and sometimes of lath, scratch, and brown coats. The boards are nailed directly to the furring, studding, etc. by means of smooth wire nails $1\frac{3}{4}$ in. long, and should be set $\frac{1}{4}$ in. apart.

**Metal Lath.**—Metal lath is made of wires woven together in a square or triangular mesh, of expanded metal, or of perforated sheet metal. Wire mesh lath is made of 18 to 21 gauge wire with about $2\frac{1}{2}$ meshes to the inch. It is made in rolls 100 ft. and 200 ft. in length and 32 in. to 36 in. in width.

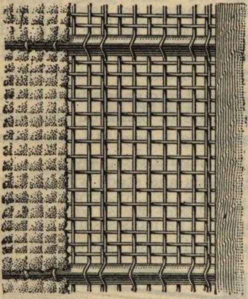


FIG. 2

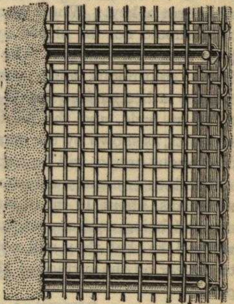


FIG. 3

It is sometimes stiffened by means of **V**-shaped bars. The lath is coated with asphaltum, painted, galvanized, or japanned to prevent corrosion. It is secured to wooden studs by means of staples or nails, and to iron furring by means of No. 18 annealed steel wire. Fig. 2 shows the back of the lath partly plastered showing the key; Fig. 3 is a view of the front, partly plastered.

*Expanded-metal lath* is formed by cutting slits in a sheet of metal and stretching it apart into the shape shown in Figs. 4 and 5. This process forms stiff sheets of lathing that require no stretching when placed on the wall. It is fastened to the studs

or furring with staples; and to metal furrings, with wire. The lath in Fig. 5 has a fine mesh and is used for interior work, while that shown in Fig. 4 has a coarser mesh and is used for exterior work. A lath stamped out of sheet steel is shown in Fig. 6.

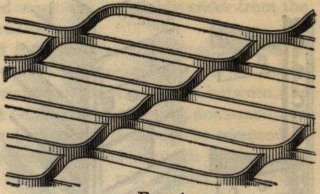


Fig. 4

**Grounds.**—Wooden grounds should be set around all openings to take the door and window architraves, and where needed for bases, wainscotings, picture moldings, etc. These should be put up solidly, straight, and true, and the plastering should be worked to them. Their thickness varies with the kind of plastering that is to be applied. For three coat, lime-plaster work on wooden laths, a $\frac{7}{8}$-in ground should be used. For two-coat work directly upon brick or terra-cotta and for hard plasters on metal lath, a $\frac{5}{8}$-in ground should be used.

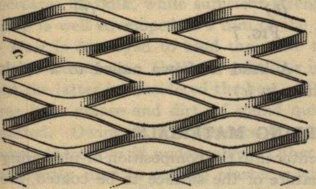


Fig. 5

**Corner Beads.** — In good work, it is customary to reinforce all projecting corners with metal corner beads, which are secured to the studding or to brick or metal surfaces in a suitable manner and are buried in the plaster with the exception of a very narrow fillet at the corner. Fig. 7 shows examples of such beads. In (*a*) is a corner bead with adjustable nailing

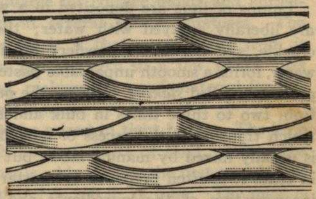
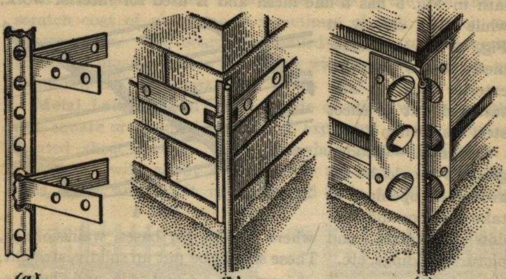


Fig. 6

cleats, which can be moved up or down and secured where the



(a) (b) (c)

FIG. 7

nails will hold the best. A bead is shown nailed to a brick surface in (*b*) and to lathing in (*c*).

## PLASTERING MATERIALS

The substances that enter into the composition of plastering mortar depend on the nature of the surface to be coated, the order in which the layers are applied, and the desired finish. For ordinary work they are lime paste, sand, hair, and plaster of Paris.

Lumps of lime are deposited in a wooden slaking box, and are liberally sprayed with water; they soon begin to swell, crackle, and fall into a powdery mass, which mixed with the water, forms a smooth impalpable paste called *slaked lime.* This process is called *slaking.* During the process, the lime increases from two to three times in bulk and much heat is given out, which transforms the excess of moisture into steam. Mortar is usually mixed by manual labor, but on extensive works and in cities it is often prepared by mortar mills, a more thorough incorporation of the ingredients and a tougher paste being produced by the machine process. It is essential that the lime should be thoroughly slaked. In much of the lime used there are more or less overburnt, hard, obstinate nodules, which resist

the permeation of water, and fail to disintegrate; these must be removed from the lime by screening, otherwise a pitted appearance of the finished work will invariably ensue from the future slaking of the particles.

*Sand* may be procured from the natural deposits in pits or along river shores. It should be clean; this can be determined by rubbing a moistened quantity of it between the hands; the grains should be sharp and angular, not round and polished. Where the sand is coarse, it should be screened to the desired fineness, by being passed through a sieve. It should be free of salt, otherwise it will attract and retain moisture; the presence of salt can be detected by tasting. Sand is mixed in the mortar for economy, and to check the excessive shrinkage of the lime paste. The sand in the mortar increases its bulk, while sufficient strength is retained, if each grain is well enveloped in a film of the paste.

*Hair* is employed to bind the paste together and to render it more tenacious. Cattle or goat hair is used for this purpose, but the latter is considered the best. Thc hair should be long, free from grease and dirt, of sound quality, and beaten up if matted. Owing to the presence of salt in salted hides, hair taken therefrom is undesirable. Other binding materials are frequently used in making plaster, such as Manila fiber, jute, and asbestos.

*Plaster of Paris* is obtained from gypsum, by gentle calcination. It is very soluble in water, which renders it unfit for external use, but it is valuable for cornice molds and enrichments, and is also used in several plastic mixtures. The great value of plaster of Paris is that paste made from it rapidly sets and acquires full strength in a few hours. Its volume expands in setting, making it a good material for filling chinks and holes in repair work.

**Mixing.**—Mortar should be mixed in tight boxes. The lime is slaked and mixed with about 2 parts of sand. When the lime has cooled hair or fiber is added. For the first coat 1½ bu. of hair are used to each barrel or 200 lb. of lime. The mass is roughly mixed with a hoe and *stacked*, or allowed to stand in a pile, for 1 wk. or 10 da., so that the moisture may reach every particle of lime and cause it to slake.

**Scratch Coat.**—Plastering is generally done in three coats on wood or metal lath and in two coats upon terra-cotta, concrete and brick surfaces. For three-coat work the process of applying and finishing the layers will be described in the order in which they are applied. The coarse stuff is taken in batches from the pile, tempered to the proper degree of firmness, shoveled into hods, carried to the rooms, and deposited on the mortar board, as at *f*, Fig. 1. A quantity of mortar is placed on the *hawk* *g*, by means of the trowel *h*, then slices of the mortar are spread firmly and evenly over the surface of the lathing.

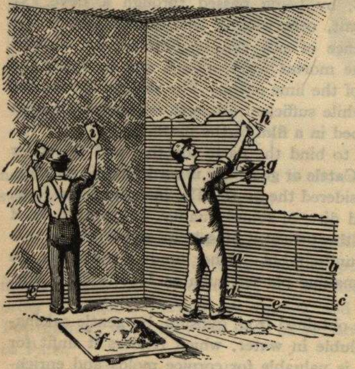


FIG. 1

The mortar should be tough, hold well together, and yet be soft enough to be pressed between the lath and bulge out behind, forming the key. The thickness of the layer should be fully ¼ in.; in cheap work it is often only a skim coat, and it is not unusual to see the lath through it. After the coat has somewhat hardened, it is scratched over diagonally by wooden comb-like blades, as *i*; from this fact the first layer is often called the *scratch coat*. The grooves fulfil the same function as the spaces between the lath, to allow a good key for the subsequent layer.

**Brown Coat.**—The second coat, consisting of a mixture of 1 part slaked lime to about 3 parts sand and ½ bu. of hair to each barrel of lime, is applied when the scratch coat has become dry; the second layer is called the *brown* or *floated* coat, because its surface is worked by means of board-shaped trowels, called *floats*. It is also known as the *straightening* coat, since all the

wall surfaces are straightened and made true. This is effected by first forming a series of plaster bands, called *screeds*, 5 or 6 in. wide, on the surface to be floated, Fig. 2. The surfaces adjacent to the angles are carefully plumbed up from the plaster ground, *e* but kept about ⅛ in. back from the face, to allow for the finishing coat. The vertical screeds *f* are formed by means of the straightedge *g*. Similar screeds *h* are formed along the ceiling angles; these screeds are made straight, and coincide

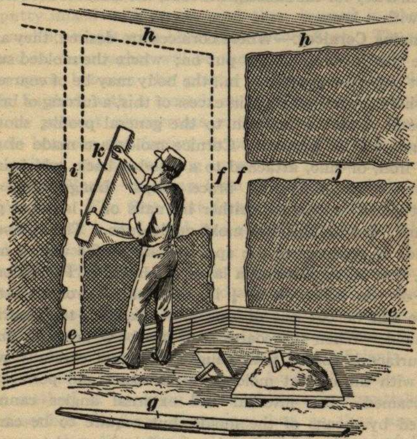



FIG. 2

with those at the opposite angles. Intermediate horizontal and vertical screeds *j* and *i* are then formed between the screeds adjacent to the ceiling and the plaster grounds; these are usually placed from 4 to 8 ft. apart, and are gauged to line by means of a straightedge. The screeds thus form a system of framing that has been reduced to a true plane; the panels are then filled in flush with the screeds, and firmly rubbed down with a two-handled float, *k*, called the ***derby***.

The surface is then worked over with a wooden hand float, the coat being firmly compacted by incessant rubbing; when the coat becomes dry during the process, it is moistened with water, applied with a wide brush. A close, firm layer can be obtained only by the thorough, laborious operation of pressing and rubbing the particles of the mortar together. The ceiling surfaces are treated in a similar manner, and the screeds are carefully leveled so as to secure true and level planes. In order to form a key for the subsequent coat, the surfaces are scratched over with a broom.

**Running Cornices.**—Where cornices are desired, they are run before the finishing coat is put on; where the molded surfaces do not project more than 2 in., the body may be of coarse stuff, but where the projection is in excess of this, a furring of brackets and lath, made to conform to the general profile, should be arranged for its support. Cornice molds are made of galvanized iron, or zinc, attached to a wooden back, which in turn is secured to guide and brace strips. Longitudinal strips are attached to the wall either by nails or a layer of plaster of Paris, and on this the mold guide runs. The coarse stuff is made to conform to the approximate profile with a muffled mold, that is, by forming a layer of plaster of Paris along the edge of the mold, about ⅛ in. in thickness; or an extended profile can be cut out of zinc and attached, temporarily, to the mold. When the coarse stuff has been properly profiled, the surface is coated with gauged stuff and carefully worked over with the correct mold, until an exact and perfect finish is obtained. The internal and external angles cannot be finished by means of the molds, but require to be carefully molded and mitered by hand, using jointing tools.

**Finishing Coat.**—The third, or finishing coat, is designated by various terms, such as skim coat, white coat, putty coat, sand finish, etc. In all cases the material is applied to the wall in the form of a stiff paste, by means of a steel trowel, and is spread uniformly over the surface to a thickness of about ⅛ in.

The *skim coat* is made of *lime putty* and beach sand that has been washed. Lime putty is slaked lime that has been run through a sieve into a tight box and allowed to stand for 10 to 14 da. The skim coat is put on with a trowel, floated

down, and then polished to a glazed surface with a trowel, the surface being kept moist by water applied with a brush

The *white* coat consists of gauged stuff made of lime putty, mixed with plaster of Paris to the proper consistency, smoothed and polished with the steel trowel; as this material sets rapidly, care must be taken to observe that the second coat is well dried, otherwise the unequal shrinkage will cause hair cracks to occur all over the finishing coat.

A *sand finish* is produced by applying a coat consisting of lime putty mixed with more sand than is used in the skim finish, and floating it with a soft pine or cork float. The coarser the sand is, the rougher will be the surface of the wall.

The space between the plaster grounds and the floor is usually finished with a scratch and a brown coat of plaster, so as to prevent air-currents entering the room from the channels between the furring strips; in cheap work this filling is omitted, the space being covered by the skirting or base.

**Two-Coat Work.**—A cheap form of plastering, is known as *two-coat work*. The first coat forms the key, but instead of being scratched it is floated to a smooth surface to take the second or finishing coat.

**Hard Wall Plasters.**—While, by the use of the best materials and proper care in preparing and applying them, a good wall may be obtained with lime plaster, there are so many uncertainties about it that numerous substitutes have been brought into use, which have proved valuable and efficient. These are known under the general name of *hard wall plasters*.

The method of applying these plasters is essentially like that described for lime plastering; but as they are more like cement than lime, the hard plasters set instead of drying. The material should be mixed fresh every hour or two, only enough water being used to give it the proper consistency. No plaster that has partially set should be remixed. When the plaster is to be applied to stone, brick, or tile, the surfaces should be sprinkled before putting on the coat. Wooden lathing should also be well moistened, so that the laths will swell before, and not after, the plaster has begun to set. The makers of hard plasters recommend that the laths be spaced $\frac{1}{4}$ in. apart and that $\frac{3}{4}$-in. grounds be used. All of these plasters,

except Adamant, can be finished with a third coat of lime putty, and sand, which should not be applied until the second coat is thoroughly dry. When not used properly, hard plasters are inferior to lime plaster, so that the manufacturers' direction for applying them should be carefully followed.

Hard plasters have many points of superiority over lime plaster, which more than balance their extra cost and which will in time probably result in their almost exclusive use. Being machined-mixed, the plaster made from them is uniform in quality and strength and has unvarying proportions of the constituents, while two batches of lime plaster may differ a great deal in this respect. They are also much harder and more tenacious, and resist fire and water better than lime, and the small quantity of water used in mixing enables them to dry much more rapidly. They are not injured by frost after they have begun to set, but should be protected from it for the first 36 hr. after being put on the walls. Heat and moisture are not readily transmitted by hard plasters, and being more dense than lime plaster, they do not absorb noxious gases nor permit the entrance of disease germs.

**Keene's Cement.**—When a highly polished and particularly hard white finish is desired, as in imitation tile wainscots in bathrooms, Keene's cement is used. It is generally applied upon a foundation of Portland cement on metal lath, and where a tile effect is desired, the surface is ruled off while soft with vertical and horizontal joints in tile size.

**Ornamental Plastering.**—Ornamental plastering embraces all cornice work, centerpieces, brackets, ornamental moldings, panel ornaments, etc. This work is generally cast and secured in place by plaster of Paris.

**Caen Stone Cement.**—Caen stone cement is used for a finishing coat when it is desired to imitate the stone of that name. Joints are cut through this coat and are filled with white mortar to represent stone work.

**Outside Plastering.**—*Stucco* should always be two-coat work. When placed on terra-cotta blocks or brickwork the material to be covered should be thoroughly wet. The scratch coat should be at least ½ in. thick and composed of 1 part Portland cement, 3 parts of sand and not more than 10% lime putty.

The first coat should be thoroughly pressed on, so as to form a good key, and well scratched before it sets. The second

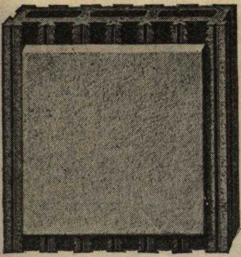


FIG. 3

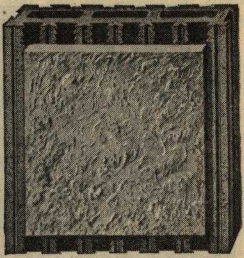


FIG. 4

coat should be $\frac{1}{4}$ in. thick and composed of 1 part Portland cement and 2 parts of sand colored as desired with yellow ochre, lampblack or any mineral pigment. For a sand finish shown in Fig. 3, use a float covered with burlap. A pleasing surface shown in Fig. 4, is obtained by stippling with a sponge full of thin cement.

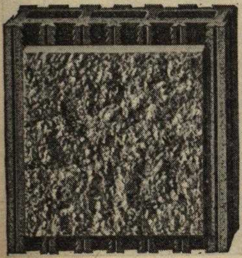


FIG. 5

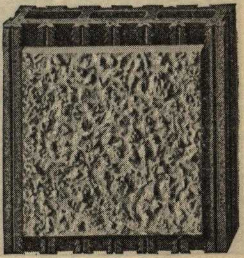


FIG. 6

Figs. 5 and 6 show different effects caused by casting or throwing the second coat mixed with pebbles, against the

scratch coat. Figs. 7 and 8 show surfaces formed of marble chips and broken stone tamped into the wet mortar with the

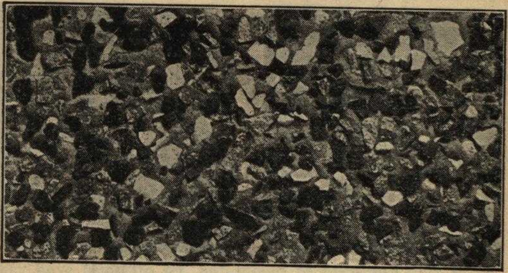


FIG. 7

float. Fig. 9 shows small pebbles pressed into the surface of the finishing coat of plaster.

**Whitewashing.**—Whitewashing is often included in the plasterer's specifications. Common whitewash is made by slaking fresh lime and adding enough water to make a thin paste. It

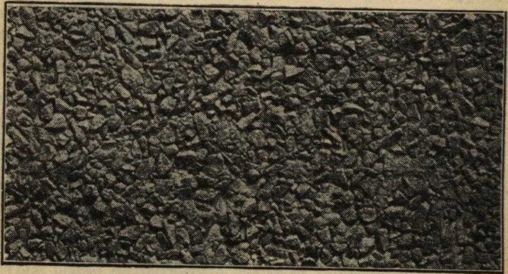


FIG. 8

is applied to walls and other surfaces with a brush. Whitewash will adhere best to rough and porous surfaces. For good

work, two coats should be put on. By using 2 lb. of sulphate of zinc and 1 lb. of salt to each ½ bu. of lime, the whitewash will be rendered much harder and will be prevented from cracking. Its durability, especially for outside work, may

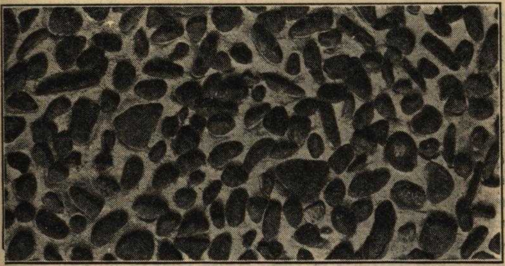


FIG. 9

be increased by mixing 1 pt. of linseed oil with each 2 gal. of whitewash. Whitewash is a very useful agent for preventlng decay of wood, and is valuable from a sanitary point of view in buildings of wood, stone, or brick.

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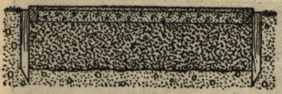
## CEMENT SIDEWALKS AND FLOORS

Where sidewalks are to be laid, the earth should be excavated to a depth of from 6 in. to 12 in., depending on the nature of the soil and the climate. Where the soil is sandy and absorbs water freely and where there is little frost, little or no foundation is necessary below the concrete. Where the soil is clayey and is impervious to water, it will be necessary to excavate for a deeper foundation, as well as to drain the excavation to a point where the water can run off. When foundations are needed, the excavation should be filled with sand, gravel, cinders, or broken stone, which should be thoroughly wetted and tamped and finished to within 4 in. of the finished surface of the sidewalk.

Place 2"×4" scantlings, which are perfectly straight and dressed on the inner face and upper edge, on top of the foundation, the proper distance apart to form the inner and outer edges of the walk as shown in the accompanying illustration.



Provide for the proper slope by setting the outer scantling 1 or 2 in. lower than the inner one. A good rule to follow is to allow $\frac{3}{8}$ in. slope to every foot of width of sidewalk. Fill in between the scantlings to the depth of 3 in. with concrete composed of 1 part of good Portland cement, 2 parts of clean coarse sand, and 4 or 5 parts of broken stone or screened gravel and tamp until the water begins to show on top. On the same day, as soon as the concrete has set, put on the finishing coat of cement, 1 in. thick, composed of 1 part of Portland cement and $1\frac{1}{2}$ parts of clean coarse sand or crushed stone screenings. This coat should be smoothed off by screeds, which should rest on the scantlings on each side of the walk. The finishing coat should not be troweled too much as this process tends to separate the cement from the sand, giving a poor wearing surface.

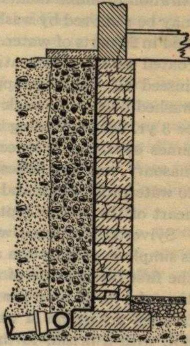
The walk should be laid in sections not larger than 6 ft. square. Every other square should be laid first and the alternate blocks next. The joints between the blocks should extend through the finishing coat and be neatly finished with a jointers' tool.

Cement walks should be covered over, as soon as completed, with canvass, tar-paper or boards, which should be kept a few inches above the surface of the sidewalk. This will protect the walk from the effects of dust, dirt, wind, the hot sun, and traffic. After the pavement has been finished for a day, it should be thoroughly sprinkled with water and kept wet for a week or more. A covering of sand $\frac{1}{2}$ in. thick and kept thoroughly wet forms a good protection but should not be applied before the surface has set hard. For floors, the same general treatment may be applied except that the work is not divided into sections but is made tight.

## WATERPROOFING WALLS

Damp cellar walls are due either to water soaking through from the outside, or to wet bottoms, from which water rises in the walls by capillary action. The decay of vegetable matter contained in dirty water generates gases injurious to health, so that the prevention of dampness in walls is a point of great importance. Provision must be made to convey the water away from the walls, as well as to make the latter damp-proof.

Earth should not be placed against the wall, but a space next to it 12 in. or 18 in wide should be filled with broken stone or gravel, with, if practicable, an open-jointed tile drain laid at the bottom, as shown in the accompanying illustration. A flat course of stone or cement slabs laid on top of the broken stone or gravel fill, extending about 2 ft. from the building, will help to keep the walls dry. Where surface water only is to be provided against, the outside of the walls and footings should be plastered thickly with 1-to-1 cement mortar; or, preferably, coated with asphalt or coal tar, applied, while hot, to the dry walls.



In order that this shall be effective, the wall should be carefully built, with the joints well pointed and the wall thoroughly dry before asphalting. Felt is often used in connection with pitch or asphalt, as in roofing, to form a waterproof coating. The waterproofing course should also extend through the walls, as shown, and under the concrete floor, which should be 3 or 4 in. thick, and laid on a 6- or 8-in. bed of broken stone.

The ascent of moisture in walls may be prevented by inserting on the footing course two courses of roofing slate, or very hard brick, laid with broken joints in cement mortar, or a few layers of tarred felt may be used.

## EFFLORESCENCE

Efflorescence, or the white coating frequently seen on the outside of stonework and brickwork, is caused by the deposition of soluble matter in the mortar, which, being dissolved in the water used in mixing, is deposited upon the surface of the wall, as the water evaporates. These deposits are, in some cases, carbonate or sulphate of soda, nitrate or carbonate of potash, or sulphate of magnesia. There is no way of preventing efflorescence except by coating the bricks with some preparation to make them impervious to water. This efflorescence may be removed by washing the walls with a dilution of muriatic acid in 20 parts of water. When clean and dry the walls may be coated with a preservative; one of the commonest being boiled linseed oil, which is applied in two coats, and, when dry, is washed over with weak ammonia. This will be effectual for 2 or 3 yr. before needing renewal. Lead and oil paint is sometimes used, but is objectionable, as it changes the color of the masonry, and also flakes off. Cabot's brick preservative is used to waterproof brick and sandstone, and is effectual where the heart of the wall is kept dry.

Sylvester's process, which has proved quite successful, and is simple in preparation and application, consists of two washes, the first being made of Castile soap and water, in the proportion of $\frac{3}{4}$ lb. of soap per gallon of water, and the second of $\frac{1}{8}$ lb. of alum per gallon of water. The soap wash is applied, boiling hot, with a brush, to the clean and dry walls, and allowed to dry 24 hr. before the alum wash—which need not be hot—is put on in the same manner. The coats are applied alternately two or three times, making the wall practically impervious.

All ordinary cements will cause efflorescence, and when such are used in stonework, the face stones should be set entirely with white Portland, Lafarge, or some other non-staining cement, mixed with sand in the proportion of 1 to 2. If this method be too expensive, the joints of the stonework may be raked out to a depth of 1 in., and pointed with a mortar made with one of these cements. Good lime mortar is often used in setting ashlar, and by some is claimed to be practically as good for the purpose, and considerably cheaper than the cements named.

# CARPENTRY AND JOINERY

## WOODS USED IN BUILDING

### DESCRIPTION OF WOODS

*White*, or *Northern*, *pine* is a light, soft, straight-grained wood, that is used in building, principally as a finishing material when work is to be painted. Its power of holding glue renders it valuable to the joiner. The tree is common in the Northern part of the United States and Canada.

*Long-leaf pine*, also known as *hard* or *Georgia pine*, has a well-marked grain, on account of which it is sometimes used as a finishing material. The wood is heavy, hard, strong, and under proper conditions, very durable, but decays rapidly in damp places. On account of its resinous nature it does not take paint well. Georgia pine is often confused with Carolina, yellow, or Southern pine, which is greatly inferior to it.

*Short-leaf pine*, or *North Carolina pine*, is neither so strong nor so durable as long-leaf pine. In appearance it is somewhat lighter in color than long-leaf pine, the fiber is softer and contains less resin than that of long-leaf pine.

*Sugar pine* grows on the Pacific coast. The wood is straight-grained and of a compact structure, is soft, easily worked, and resembles white pine. It is used in carpentry and for interior finish.

*Oregon pine*, sometimes called *Douglas fir*, while really belonging to the spruce family, so closely resembles pine that it is so called. While nearly as strong as Georgia pine, it is much lighter in weight, and more easily worked. Owing to the long lengths in which it can be obtained, it is in demand for flagstaffs and long framing.

*Black spruce*, growing in the Northeastern states and Canada, is light in weight, reddish in color, and though easy to work, is very tough in fiber. It is largely used for submerged cribs and piles, as it not only preserves well under water, but also resists the destructive action of parasitic crustacea.

*White spruce*, scarcely distinguishable from black, is largely used throughout the Eastern states for all classes of lathing, framing, and flooring.

*Hemlock* is like spruce in appearance, but much inferior in quality, is brittle, splits easily, and liable to be shaky. It is only used as a cheap, rough framing timber.

*White cedar*, a soft, light, fine-grained, and very durable wood, lacking strength and toughness, is much used for boat-building, cigar-box manufacture, shingles, and tanks.

*Red cedar*, a smaller tree than white cedar, similar to it in texture but more compact and durable, is of a reddish-brown color, and possesses a strong, pungent odor, which repels moths and other insects, making it extremely valuable as shelving for closets, and linings for chests and trunks.

*Cypress*, a wood very similar to cedar, growing in the Southern part of the United States, is one of the most durable woods and well adapted for outside or inside work. Special care must be taken in seasoning it, as it tends to sliver and become shaky if forced in the drying.

*Redwood*, the name given to one of the species of giant trees of California, grows to a height of from 200 to 300 ft., its trunk being bare and branchless for one-third of its height. The color is a dull red, and the wood, resembling pine, is used in the West the same as pine is in the East. As an interior finish it is capable of taking a high polish, and its color improves with age.

*White oak* is the hardest of the American oaks, and grows in abundance throughout the eastern half of the United States. The wood, heavy, hard, cross-grained, strong, and of a light yellowish-brown color, is used where strength and durability are required, as in cooperage and carriage making, and is especially prized as a material for cabinetwork, when the log is quarter-sawed. In first-class work, it is usually cut into veneers $\frac{3}{16}$ in. thick, which are laid on cores of white pine or chestnut. The silver grain and the high polish that the wood is capable of receiving make it one of the most beautiful used in joinery.

*Red oak* is darker and redder, coarser, more brittle, and of a more porous texture than white oak. It is much used for the interior finish in buildings.

*White ash*, the wood of a large tree growing in the colder portions of the United States, is heavy, hard, very elastic, and exceedingly tough. Its grain is coarse, and very much like bastard-sawed oak in appearance. It is used for interior trim; and when properly filled can be brought to a high polish. Ash is sometimes used for cabinetwork, but its tendency to decay and become brittle renders it unfit for structural work. *Black ash* has a brown, cedar-like appearance.

*Locust* is one of the largest forest trees in the United States, and furnishes a wood that is as hard as white oak. Its principal use is in exposed places where great durability is required; also where it comes in contact with the ground, as in posts. It is also very durable in damp places. Its hardness increases with age.

*Black walnut* is heavy, hard, porous, and of a purplish color, marked by a beautiful wavy grain. Strong, durable, and not subject to the attacks of insects, it is used generally for small cabinetwork, gun stocks, and interior decoration. The knotted roots of the tree furnish material with a curly grain, called *burl*, which is cut up into veneers.

*Cherry.*—The wood of the wild cherry is moderately heavy, hard, very durable, and has a close, fine grain. It is susceptible of a high polish, and is much used for fine interior trim and cabinetwork. Cherry stained black to imitate ebony cannot be detected, except by scraping the polished surface. It is largely used for piano cases, furniture, etc.

*Birch* strongly resembles cherry in texture, and in some species in color also. *Black* or *cherry birch* furnishes the best lumber, but is not as durable as ordinary birch, and is more affected by atmospheric influence.

*Sugar*, or *hard maple* is a light-colored, fine-grained, strong, and heavy wood. The medullary rays are small and distinct, giving a silver grain to the quarter-cut lumber. It is used for flooring and interior trim, but for fine work it is used as veneer. *Curly maple* is maple in which the waviness of the grain is similar to that obtained from the roots of the walnut tree. *Bird's-eye maple* is produced in old trees by the circular inflection of the fibers. Though both the curly maple and the bird's-eye are practically distorted fibers, and reduce the

strength of the wood, they are highly prized in the cabinet-maker's art.

*Chestnut* is comparatively soft, close-grained, and, though very brittle, is exceedingly durable when exposed to the weather, and has recently come into use for interior finish.

*Poplar*, or *whitewood*, a lumber of the tulip tree, is a large straight forest tree, abundant in the eastern part of the United States. It is light, soft, very brittle, and shrinks excessively in drying. In color it varies from white to pale yellow. The cheapness and ease of working poplar cause it to be largely used for the cheaper grades of carpentry and joinery work, but it warps and twists exceedingly in even slight atmospheric changes.

*Buttonwood*, also called *sycamore*, is the wood of a tree generally known as the *plane tree*. It is heavy, hard, of a light-brown color, and very brittle. The grain is fine, close, and susceptible of a high polish. It is very hard to work, liable to decay, and has a strong tendency to warp and twist under variations of temperature. On this account it is best used for veneered work.

*Apple* and *pear* trees furnish wood used for tool handles, plane stocks, and small turned work. Neither is much used in building. Pear wood is sometimes used for carved panels, on account of its yielding so easily to edge tools.

*Boxwood* is close-grained, yellow in color, and on account of its lack of shrinking and warping tendencies, very desirable for small carved and turned work. It is particularly useful in wood engraving.

*Basswood* is the name given to the *American linden* tree. In general appearance it strongly resembles pine, but is much more flexible. It has a great tendency to warp, and will shrink both across and parallel to the grain. It is much used for curved panels.

*Mahogany* is a native tree of the West Indies and Central America. The color, grain, and hardness of the wood vary considerably according to its age and locality of growth. It is used for the highest grades of joiner work. The straight-grained varieties do not warp or shrink materially with atmospheric changes, while the cross-grained varieties warp and

twist to a remarkable extent, and can, therefore, be used to advantage only when veneered upon some more reliable wood. The soft and inferior grades from Honduras and Mexico are called *baywood* to distinguish them from the rich deep-red San Domingo or Spanish mahogany. *Prima Vera* or *white* mahogany is of a creamy color, very much like the baywood in texture, and makes a beautiful finish for fine work.

*Rosewood* is a heavy, hard, and brittle wood, from several trees native to the tropical countries. It has a beautiful grain, alternating in dark brown and red stripings, which when well polished makes the surface one of the handsomest products of the vegetable world. As a veneer, it is applied to all kinds of cabinet, furniture, and joinery work where richness and durability are required, regardless of expense.

*Ebony*, a dark, almost jet-black wood, native to the East Indies and parts of Africa, is heavy, strong, and exceedingly hard, with an almost solid annual growth. It takes a high polish, and is used in cabinetwork.

*Lignum vitæ* is an exceedingly heavy, hard, and dark-colored wood. It is very resinous, difficult to split, and soapy to the touch; it is used mostly for small turned articles, tool handles, and pulley wheels.

*Sweet-* or *red-gum*, a tree of large growth, is very plentiful in the Central and Eastern States. It is soft in texture, but strong and tough, and strongly resembles light-colored walnut. It presents a very handsome appearance when selected and well finished, but has a tendency to warp and shrink, which makes it unreliable, unless used in veneered work. It is largely used for fine interior trim, and cabinetwork.

## RELATIVE HARDNESS OF AMERICAN WOODS

Woods may be divided into four classes in considering their hardness, using the term hardness in its literal sense. The *very hard woods* are hickory, hard maple and the best qualities of oak. The *hard woods* are oak, cherry, ash, birch, black walnut, and sycamore. The *medium hard woods* are the Southern and Western pines, Douglas fir, and sweet gum. The *soft woods* are white pine, spruce, hemlock, cypress, redwood, poplar and chestnut.

## SHRINKAGE OF WOODS

When seasoning in the open air, boards shrink in width from 3% to 10%. The approximate shrinkage for different woods is given in the accompanying table.

### TABLE OF SHRINKAGE OF WOODS

| Kind of Wood | Per Cent. of Shrinkage | Kind of Wood | Per Cent. of Shrinkage | Kind of Wood | Per Cent. of Shrinkage |
|---|---|---|---|---|---|
| White pine.... | 3 | Ash........ | 5 | Sycamore... | 5 |
| Spruce........ | 3 | Elm........ | 5 | Birch....... | 6 |
| Hemlock..... | 3 | Walnut..... | 5 | Chestnut ... | 6 |
| Cypress....... | 3 | Poplar...... | 5 | Hickory .... | 6 to 10 |
| Long-leaf pine. | 4 | Maple...... | 5 | Oak........ | 6 to 10 |
| Short-leaf pine | 4 | | | | |

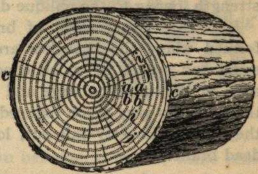
## QUALITIES OF TIMBER

The best timber is obtained from mature trees, the fibers of which have become compact and firm, both by the drying up of the sap and by the compressive action of the bark. There is a great difference both in appearance and strength between the heart-wood, or *duramen*, and the sap-wood, or *alburnum;* in the former, the fibers are firm and dense, and possess a deep color; in the latter, they are open, porous, and filled with sap, and are usually of a pale color. The heart-wood is much stronger, and less liable to decay and to the attacks of insects, than sap-wood.

The *medullary rays* consist of vertical layers or sheets, radiating from the center, and connecting the pith with the bark. They are not, however, continuous, but are broken by the interweaving of the fibers. Those rays extending from the pith to the bark are called *primary* rays; those extending through only a portion of the stem are called *secondary* rays. The medullary rays are prominent in oak, beech, and sycamore, but are not so well defined in birch, chestnut, and maple. It is the presence of these medullary rays, sometimes called *silver grain*, that gives so much beauty to quartered oak.

The accompanying figure represents a section of an oak or ash tree of 13 yrs'. growth, the coarse texture formed of the large sap vessels being shown at *a*, the closer texture at *b*, the bark at *c*, the primary medullary rays at *i*, and the secondary ones at *j*.

**Selecting the Stock.**—In good lumber for building purposes, the heart-wood should be sound and mature, the sap-wood, or layers next the bark, being entirely removed. The wood should appear uniform in texture, straight in fiber, be free from large or loose knots, flaws, shakes, or any kind of blemish. When the rings are close and narrow, they denote a slowness of growth, and are usually signs of strength. When freshly cut, the wood should smell sweet; a disagreeable smell is a sign of decay. The surface, when sawed, should not appear woolly, but be firm and bright, and it should not be clammy and choke the saw. When planed, the wood should have a silky appearance; the shavings should come off like ribbons and stand twisting around the fingers. When the wood appears dull and chalky, and the shavings are brittle and friable, it is not first-class stock. Good lumber should be uniform in color; when blotchy or discolored it signifies a diseased condition.




**Imperfections.**—There are various defects in timber, which may be caused either by the nature of the soil in which it grew or by accidents due to storms, etc.

*Heart shakes* are cracks or partings of the fibers, radiating from the center of the tree. They are common in nearly all classes of timber, and are caused by the shrinkage of the inner layers incidental to loss of vitality; the cracks are wider toward the heart.

*Star shakes* are cracks radiating from the center, but are wider toward the bark; they are caused by the rapid drying of young timber while it is full of sap.

*Cup shakes* are curved splits that separate the layers, and are caused by severe wind storms.

*Rind galls* are curved swellings, caused generally by resinous layers forming over a wound where a branch has been broken off.

*Foxiness* is a yellow or red coloring, signifying the early stages of decay.

*Dry rot* is a fungus growth, and can be discovered by a black-and-blue tinge; the end wood is crumbly and crisp. Timber thus affected is of no permanent value, as the rot continues until the fiber becomes powder.

*Twisted fibers* are caused by the twisting tendency of winds blowing generally in one direction; such timber possesses little strength, owing to the oblique direction of the fibers.

*Knots* are either stubs of branches or the gnarly growth formed where the branches are lopped off. Knots may be small and sound, in which condition they are not objectionable, or they may be large and loose; if large, the strength of the timber is very much reduced, and, if loose or dark in color, they will ultimately fall out, loose knots being the stubs of dead branches.

## QUARTER AND BASTARD SAWING

The term *quarter sawed* signifies that the log is cut into quarters before being reduced to boards, while the term *bastard sawed* denotes that all the saw cuts are parallel to the squared side of the log. In genuine quarter sawing (also called rift sawing) the cuts should be as nearly as possible at right angles with the circles of growth, or annual rings, or parallel with the medullary rays *a*, as shown in Fig. 1; while in bastard sawing, the cuts are nearly parallel with the annual rings and expose the edges of the medullary rays *a* and the face of the annual rings, as shown at *b′* and *c′* in Fig. 2. The advantages in quarter sawing material having well-defined medullary rays are that it wears better, shrinks less, and the silver grain presents a very fine effect.

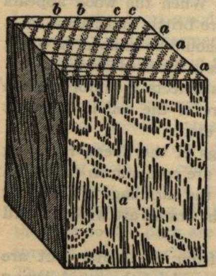


FIG. 1

Fig. 3 illustrates four methods of cutting the boards from the "quarters." The tree is first quartered by cutting it on lines *ab* and *cd*, after which the quarters may be reduced to boards by any of the methods shown. The best results are secured by the method shown between *a* and *c*, as the saw cuts are nearly on radial lines, and the full face of the silver grain will be exhibited. The section between *c* and *b* shows the next best method; fewer triangular strips are formed, but the boards will not present as rich an effect, as many of the medullary rays are cut obliquely.

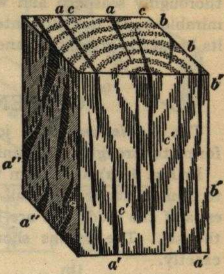



FIG. 2

The result of cutting the section between *a* and *d*, while economical in material, will not give as good results as the two former methods. Where thick material is desired, the system of cutting shown on the section between *d* and *b* is adopted, the cuts being made in the order in which they are marked.

As before stated, the best effects are produced when the saw cuts come parallel, or nearly so, with the medullary rays: this is shown in Fig. 1. These rays on the end section are marked *a*, and are seen to cross the annual rings *b* and *c* at nearly right angles, so that the edges of these rings are exposed on the face, and through which the silver grain *a'* emerges. The value of quarter sawing does not consist merely in exposing the beautiful figuring of the material, but it is found that the quartered material shrinks less than one-quarter as much in width as the bastard-sawed stock. This is an invaluable virtue, which the joiner and

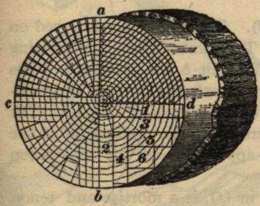



FIG. 3

cabinetmaker are not slow to appreciate. Quarter-sawed stock is also less sensitive to changes of temperature, and when once thoroughly seasoned and well put together, it makes an admirable finish both for interior treatment and furniture, and its beauty is greatly enhanced with age.

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## CARPENTRY JOINTS

The *mortise-and-tenon* joint is used in several different forms to strengthen the union of two pieces of timber.

In Fig. 1 (*a*) are shown two simple forms, such as are used to connect studs *a* to a sill *b*. The *tenons c* are formed on the ends of the studs and are let into the *mortises*, or holes, *d*, in the sill. The tenons should be made to fill the mortises exactly.

In (*b*) is shown a form of mortise-and-tenon joint that is used in securing a girt *a* to a corner post *b*. When the tenon is fitted into the mortise, hardwood pins *e*, are driven into the holes *c*, which correspond with the holes in the tenon. The sides *d* are called the *cheeks* of the mortise.

The *fox-wedged joint*, shown in (*c*), is used to secure the tenon in a mortise that is not cut through. Thin wedges of hardwood are placed in saw cuts in the end of the tenon. On driving in the tenon the wedges cause it to expand and fit tightly in the mortise, which is dovetailed or widened out at the back.

The *tusk tenon* is shown in (*d*). This tenon is reinforced on the under side by the tusk *e*. The joint *a* is used in framing tail-beams into headers, and the joint *b* for framing headers into trimmers. Where the tenon *d* extends through the trimmer, it is secured by a wooden *draw-bore pin* or *wedge c*. The bearing of the joists and headers is on the under side of the tusks *e*. In (*e*) is shown the application of the tusk-tenon joint.

A *bevel-shoulder joint*, shown in (*f*), is a mortise and tenon used to unite inclined to upright or horizontal pieces. It is made by cutting beveled shoulders on the inclined piece and a corresponding sinking in the cheeks of the mortise of a post or beam.

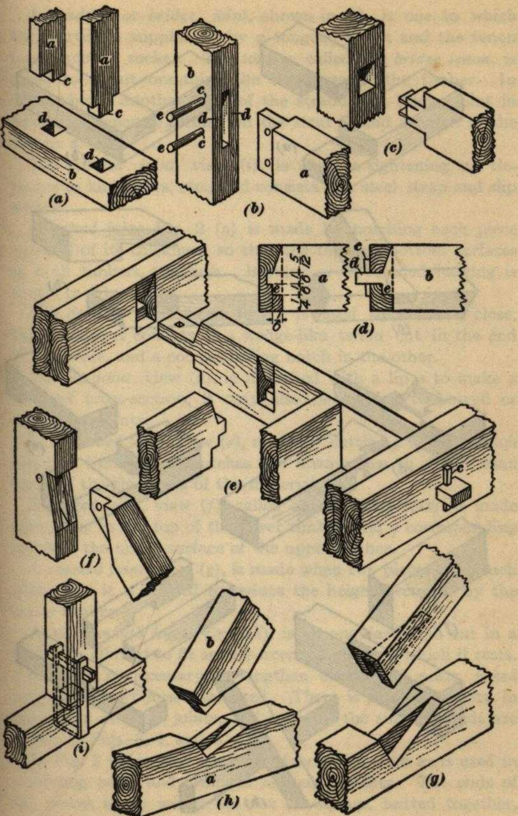


FIG. 1

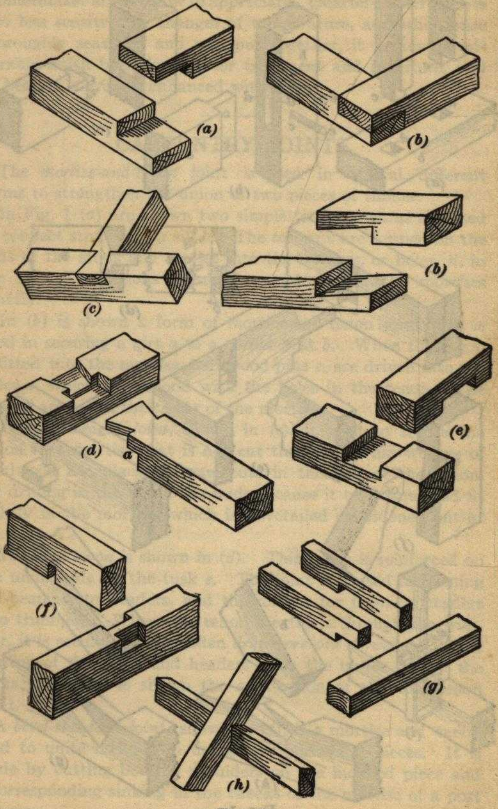


FIG. 2

A *straddle*, or *bridge, joint*, shown in (*g*), is one in which the mortise is supplanted by a tongued notch and the tenon by a grooved socket. The *tongue*, called the *bridge tenon*, is equal to about one-third the thickness of the timber. In (*h*) is shown another form of the straddle or bridge joint in which the tenon is formed on the strut *b*, and a notch in the timber *a*.

The *cottered joint*, view (*i*), is used in tightening up tie-beams to king posts, etc., and consists of a steel strap and slip wedges.

A *halved* joint Fig. 2 (*a*) is made by notching each piece one-half of its thickness, so that the top and bottom surfaces of both timbers are flush. Beveled or dovetailed halving is shown in (*b*).

The *dovetail joint* shown in (*c*), is used to obtain a close, rigid union; it consists of a wedge-like tenon cut in the end of one piece, and a corresponding notch in the other.

The *lip joint*, view (*d*), is furnished with a lip *a* to make a stronger cross-section; it may also be applied to halved or dovetailed joints.

In a *notched joint*, view (*e*), made by cutting a notch in each piece of timber, the notches are always less in depth than one-half the thickness of the material.

A *cogged joint*, view (*f*), called also a *corked joint*, is made with a cog in the top of the lower timber, and a corresponding notch in the under surface of the upper timber.

A *checked joint*, view (*g*), is made when two pieces cross each other, and it is desired to reduce the height occupied by the upper timber.

A *bird's-mouth joint*, view (*h*), is an angular notch cut in a timber to allow it to fit snugly over the piece on which it rests.

When it is necessary to lengthen beams and posts, *fished joints* and *scarf joints* are used. There is a great variety in the design of these joints, and a few of the simpler kinds are shown in Figs. 3, 4, and 5.

In Fig. 3 (*a*) is shown a plain *fished* joint such as is used in extending posts and studs in balloon framing. The ends of the pieces to be joined are cut off square, butted together, and secured by nailing boards on their opposite sides. These

boards are called *fish-plates.* In (*b*) is shown a fished joint formed by placing iron fish-plates *a* over the faces of the timbers and bolting the whole firmly together. A *fished-and-tabled joint* is shown in (*c*). This joint is designed for use where a tensile stress is likely to occur. The fish-plates have projections *def* worked on them and let into the timbers that are joined; these fish-plates are then bolted or spiked to the timbers. The projections on the fish-plates and the bolts and spikes will have to be sheared off before the joint fails. In

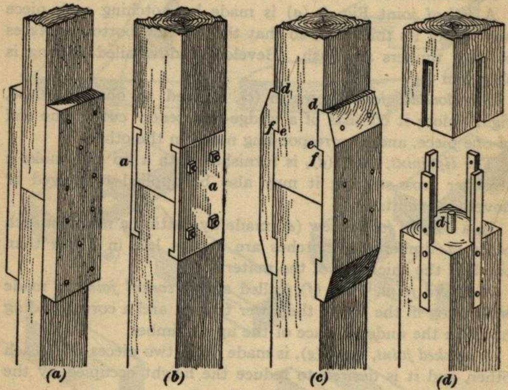


FIG. 3

(*d*) is shown a joint designed to resist tension; it has four, small, iron fish-plates let into the surfaces and spiked to them. The dowel *d* fits into holes bored in the ends of the timbers.

Scarfed joints are made by fitting two timbers together in the direction of their length and securing them by means of bolts, keys, etc. and without the use of fish-plates. The form shown in Fig. 4 (*a*) is used where the timber has to be lengthened; this joint forms a rigid splice. A *lap joint,* shown in (*b*), is made by laying one end of a timber over another

and fastening them together with bent straps, which have screw ends by which they may be tightened. The efficiency

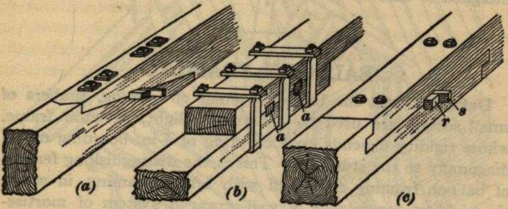


FIG. 4

of this joint can be increased by inserting hardwood tongues *a* across the faces in contact.

A typical scarf joint is shown in (*c*) and is sometimes called a *tabled scarf joint.* After the timbers are fitted together, the wedges *r* and *s* are driven in and the timbers bolted together. Washers should always be placed under the heads of the bolts to prevent the crushing of the wood. This joint is adapted to resist compression or tension.

A combination of fished and scarfed joints is used in various forms. In Fig. 5 (*a*) is a scarfed joint reinforced with iron

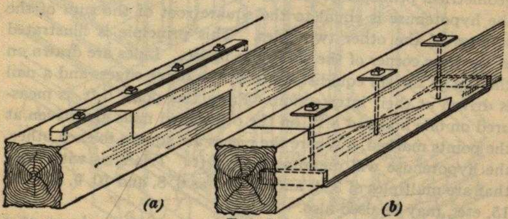


FIG. 5

fish-plates bolted to the joint and is designed to resist compression or tension. In (*b*) is shown a scarfed joint with a

fish-plate on the under side; this joint may be used where a transverse load occurs. The fish-plate on the under side is designed to take up the tension.

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## BALLOON FRAMING

**Definition.**—In the balloon system of framing, timbers of small section are used to construct a light, skeleton frame, whose rigidity depends on a covering of $\frac{7}{8}$-in. boarding nailed diagonally to the studding. This is the distinguishing feature of balloon framing compared with braced framing, in which the rigidity depends on a well-arranged system of mortise-and-tenon joints and diagonal bracing, irrespective of covering. A practical application of balloon framing is shown in Fig. 1 which is an isometric sketch of part of a building during erection.

**Sill.**—After the wall *a* is completed, the 4″×8″ *sill b* should be laid in a bed of mortar, tamped, and carefully leveled, as from it all heights are measured. The edge should be kept back from the face of the wall, so that the outside boarding or *sheathing* will be flush with the latter. The sill should also be accurately squared, to obtain satisfactory results. A very simple and practical method of squaring depends on the geometrical principle governing right-angled triangles; namely, the hypotenuse is equal to the square root of the sum of the squares of the other two sides. This principle is illustrated at the near corner of the sill in the figure. Lines are drawn on the top of the sill equidistant from the outer edges, and a nail is driven at their intersection. From this point 6 ft. is measured on one line and 8 ft. on the other, and nails are driven at the points marked. Where the pieces are square to each other, the hypotenuse will measure just 10 ft. Triangles with sides that are multiples of 3, 4, and 5, such as 6, 8, and 10, 9, 12, and 15, etc., may be used also.

The sill is halved and spiked at the corners as shown at *c* and where the pieces composing it cannot be obtained in sufficient lengths, the sill is pieced out by means of the beveled splice, as shown at *d*. In exposed situations where high winds

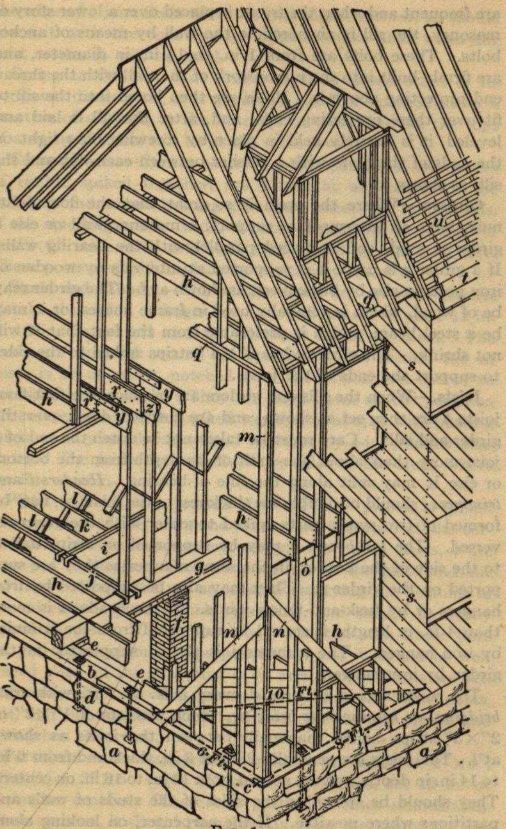



FIG. 1

are frequent and when the frame is placed over a lower story of masonry, the sill is anchored to the wall by means of anchor bolts. These bolts are from 1 in. to 1½ in. in diameter, and are firmly built into the masonwork of the wall with the thread end projecting above it. Holes are then bored into the sill to fit over these projecting ends, and, after the sill is laid and leveled, it is securely held in place by screwing nuts tight on the ends of the bolts with a washer between each nut and the sill, as shown at *e*.

**Girders.**—Where the span is so great that the floor joists must have an intermediate support, a masonry wall or else a girder is used, and is placed parallel with the bearing walls. If a girder *g* is used, it is supported at intervals by wooden or iron posts or else by brick piers, as shown at *f*. The girder may be of wood, which is generally used in frame houses, or it may be a steel beam, which is preferable from the fact that it will not shrink. The girder *g* has 2″×4″ strips spiked to the sides to support the ends of the joists.

**Joists.**—When the sills and girders are in place, the first-floor joists *h* are then set as shown, and are notched down over the girder and sills. Care must be taken not to notch the end of a joist more than about one-sixth of its depth from the bottom or else it may split along the line of bearing. *Headers i* and *trimmers j* should be double the thickness of the joists or, may be formed of two single joists spiked together with the grain reversed. The *tail-beams k* may be supported on strips nailed to the side of the header, in the same manner as they are supported on the girder *g*. They may also be supported by irón hangers or by tusk-and-tenon joints. If the header *i* is more than 4 ft. in length, it should be supported from the trimmer by iron hangers. The trimmer *j* is shown supported on the girder by iron hangers.

The joists should be braced every 5 ft. or 7 ft. with *cross bridging*, or *herring-bone bridging*, which consists of 1″×2″ or 2″×3″ strips nailed diagonally between the joists as shown at *l*. The joists are generally 2 in. or 3 in. thick and from 6 in. to 14 in. in depth, and are spaced from 12 in. to 16 in. on centers. They should be spiked to the sides of the studs of walls and partitions where possible. If the carpenter, on looking along

the edge of a joist finds that it is curved, or *crowned*, he should place it with the convex edge uppermost so that when the joist settles it will be level.

Owing to the fact that timber is often sawed scant of its supposed dimensions, it is generally *sized*, or notched down a fraction of an inch, at the bearings so that when set the tops of a series of joists will be at the same level.

**Corner Posts.**—Corner posts *m*, which consist of two pieces of timber spiked together, are placed at all corners of the building and where bearing partitions meet the outer walls. If the studding is 4 in. wide, the corner post will be formed of a 4″×6″ stick with a 2″×4″ stud nailed on the long side. These posts are held in place by temporary *braces n*.

**Studs and Ribbon.**—The outside studs are cut with notches to take the *ribbon* or *ledger board o*, and are set in place 12 in. or 16 in. on centers and the ribbon is nailed to them. The studs are doubled around all openings. The second tier of joists is set in place, notched over the ribbon and spiked to the sides of the studs. They are sized down on the partition either lapping and being spiked together as at *z*; or with butting joints as at *y* and being spliced together by $\frac{7}{8}$-in. wooden fish-plates. The joists are nailed to the sides of the studs where possible as at *r*.

**Plate.**—The *plate q*, formed of two 2″×4″ pieces, is spiked down on top of the posts and studs, and is lapped at the corners and elsewhere where necessary. The attic joists, *h* are then put in position, their ends resting on the plate and the partition. The joists act as *collar beams* tying the bottoms of the rafters to prevent their spreading, and should be firmly spiked to them. Care should be taken that the frame does not get out of plumb, or perpendicular, and it should be well braced until all the sheathing is on and the partitions are set.

**Braces.**—In some cases, braces *n* are let into the corner posts, sills, and intermediate studs and keep the corners plumb and strengthen the frame.

**Partitions.**—The supporting partitions are made of 2″×4″, 3″×4″, or 2″×6″ studs of hemlock or spruce, set 12 in. or 16 in. on centers. Where one partition comes immediately above another, it should bear directly upon the cap of the one

below, which is made of two partition studs laid flatwise. Studs should be doubled around all openings and openings over 3 ft. wide should have a simple truss formed above them as shown at *a*, Fig. 2. Partitions, if more than 8 ft. in height, should be bridged with pieces of studding as at *b*.

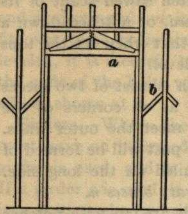


FIG. 2

**Sheathing.** — Before the building is sheathed, the corner posts *m*, Fig. 1, should be carefully replumbed and adjusted by means of a plumb-bob suspended from the wall plate and run down to the sill, when the most accurate adjustment can be made. The sheathing *s* should be placed diagonally at an angle of 45°, and be well nailed to each stud with two or three nails, according to the width of the board. The butt joints should be cut on the center line of the studs. With boarding thus placed, well fitted and nailed, the structure is completely braced in a very simple and effective manner. The outer surface should be covered with a layer of heavy building paper lapped at the edges and tacked in place. Paper, being of close texture and a non-conductor of heat, makes an excellent covering material, rendering the building warmer in winter and cooler in summer.

Sheathing consists of a cheap kind of lumber, $\frac{7}{8}$ in. thick, but the boards should be dressed to an even thickness. The roof is also covered with sheathing boards, but when tiles, slate, or shingles are used, strips are sometimes nailed horizontally to the rafters as shown at *u* and spaced at a distance apart equal to the distances between nailings of the roofing material. When rafters project beyond the face of the building, they should be covered with sheathing for their full projection as at *t*. Sheathing should be placed on each side of all valleys; for 8 or 10 in. on each side of the ridge and around all chimneys, as at *b*, Fig. 3.

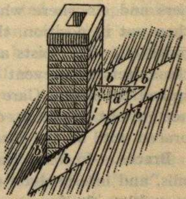


FIG. 3

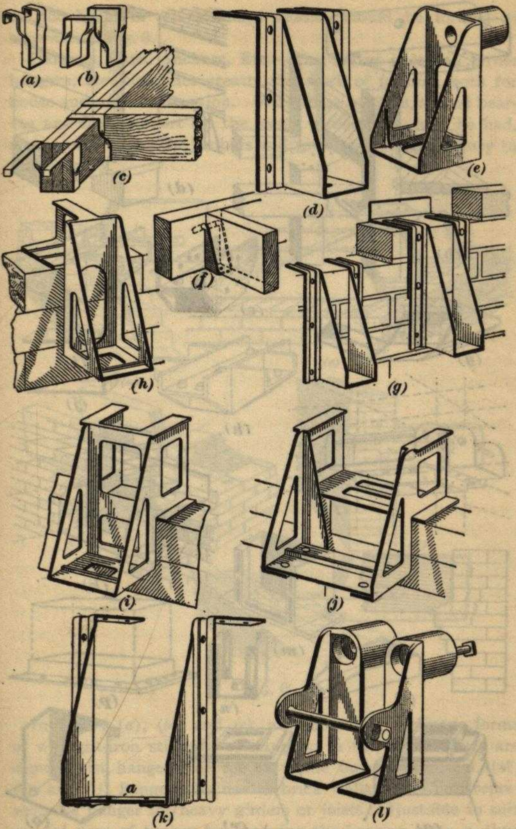



FIG. 4

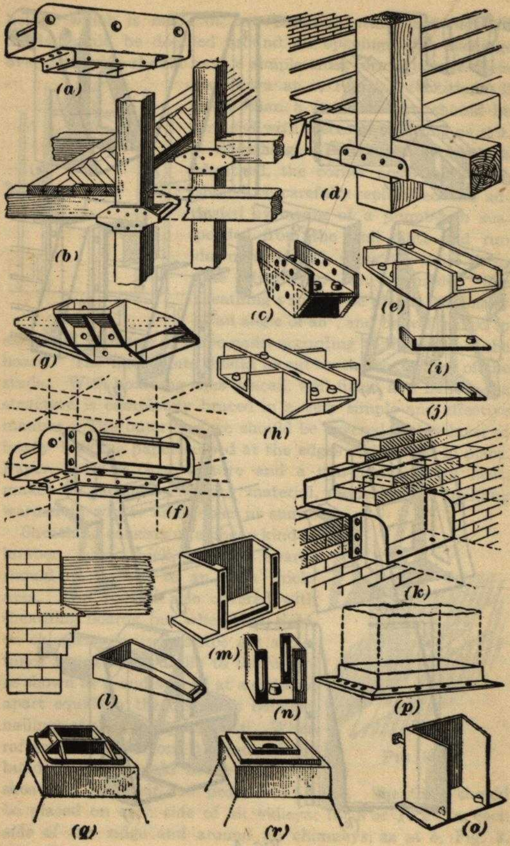



FIG. 5

At the backs of all chimneys saddles should be formed as shown at *a*, Fig. 3.

**Hangers, Caps, Anchors, Etc.**—The use of joist and girder hangers, etc. simplifies greatly the work of framing both for house and mill construction. With these hangers, a good bearing and firm support for the joists, girders, etc. may be had, and in case of fire the timbers will give way without injury to the masonry.

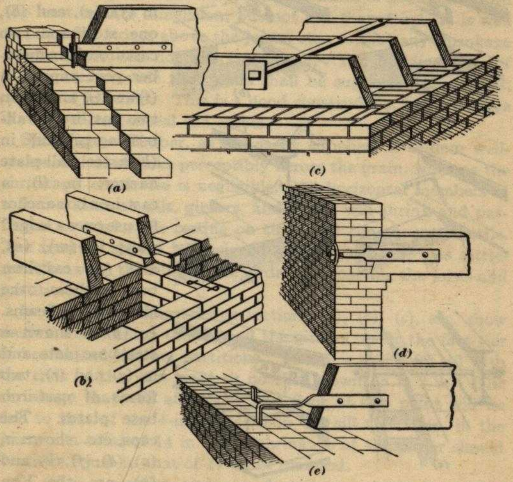



FIG. 6

In Fig. 4 (*a*), (*b*), and (*c*), are shown the ordinary forms of wrought-iron stirrups, or hangers; in (*d*), (*e*), and (*f*) are shown joist hangers for use in frame buildings; in (*g*), (*h*), (*i*), and (*j*) hangers for use in brick walls. In (*k*) is represented a hanger for heavy girders or joists, adjustable to suit several sizes of timber by changing the bearing plate *a*, thus

serving the same purpose as that shown in (*l*), which represents a hanger made in right and left parts, and fastened together by a bolt. Of the hangers shown, (*d*), (*g*), and (*k*) are the Van Dorn; (*e*), (*h*), (*i*), (*j*), and (*l*), the Duplex; and (*f*), the Goetz, types.

In Fig. 5 (*a*), (*b*), and (*c*) are represented two-member post caps; one is steel and the others are cast iron. In (*d*) and (*e*) are shown three-member post caps; in (*f*), (*g*), and (*h*), one steel and two cast-iron four-member post caps. In (*i*) and (*j*) are shown two cast-iron wall-bearing plates; in (*k*), a steel wall-plate hanger; in (*l*), a cast-iron box anchor for use over a ledged wall; in (*m*), (*n*), and (*o*), cast-iron bar anchors, the latter for **I** beams. In (*p*) is shown a steel base plate, and in (*q*) and (*r*), two forms of cast-iron base plates. The caps, etc.. shown in (*a*), (*d*), (*f*), (*k*), and (*p*), are the Van Dorn; and those in (*b*), (*c*), (*e*), (*g*), (*h*), (*l*), (*m*), (*n*), and (*o*), the Goetz styles.

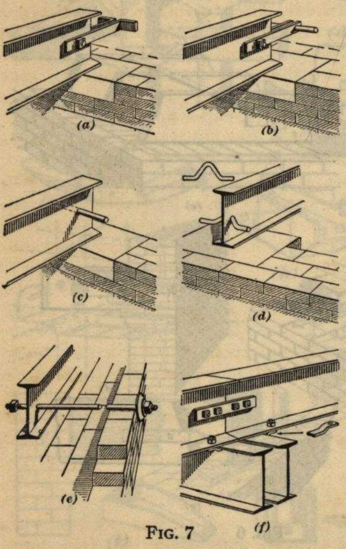


FIG. 7

In Fig. 6 are shown the common forms of anchors for tying wood floor joists to masonry. They are made of wrought bar iron about $\frac{1}{4}$ in.$\times$2 in., and about 2 ft. long. Where the anchor passes through the wall, as in (*d*), a cast-iron washer, or plate, holds the anchor in place.

In Fig. 7 are shown several forms of ties for anchoring **I** beams, channels, etc.; (*a*), (*b*), (*c*), and (*d*) represent ordinary wall anchors; (*e*) is a tie-rod anchor running through the wall, and (*f*) shows the upper **I** beams connected by a fish-plate and secured to the girder by *clips*.

When wall boxes or hangers are not used, templets, or bearing stones, should be placed under the ends of beams and girders, to distribute the weight evenly on the wall. They should be of tough stone, having a thickness of about one-third the least surface dimension, but not less than 4 in. It is well to place flat stones above the joists, etc., so that any shrinkage in the latter will not affect the wall. The building laws of some cities provide that joists shall be supported on corbels, at least 4 in. wide. This is a good construction, but a cornice is required to conceal the corbel.

**Shrinkage.**—Timber, as ordinarily supplied, is seldom well-seasoned. It shrinks perceptibly across the grain, whereas the shrinkage lengthwise is negligible. All horizontal members of a frame, such as sills, girders, and joists, will shrink and partitions or stud walls resting on them will consequently settle. The framing should be designed so as to equalize this settlement between the sill and the girders, supporting the joists and partitions.

In Fig. 8 the diagrams or sections (*a*), (*b*), (*c*), etc. show methods of framing the sill and the girders under the first tier of beams and bearing partitions. In (*a*) is a 4″×8″ sill with the ends of the joist sized or notched down on it 2 in. The shrinkage that will affect the first floor at this point will be due to that of the 4-in. material in the sill and 10-in. in the joist, or a total of 14 in. The shrinkage at the girder should be made equal to that of 14 in. of material.

In (*b*) is a wooden girder, such as is commonly used, with two 3″×4″ strips bolted to the lower edges. By sizing down the ends of the joists 2 in. on these strips the floor is subject to the shrinkage of 14 in. of material, 4 in. in the strips and 10 in. in the joist. This equalizes the shrinkage between the girder and the sill.

In (*c*), an **I**-beam girder is shown with 3″×4″ strips bolted to its lower part so that the shrinkable material will be 10 in.

for the joists, which are sized down 2 in. on the strips, and 4 in. for the strip.

In (*d*), the joists are shown supported on hangers suspended from a girder that is 10 in. deep. The shrinkage that will affect the first floor at this point is due to the lower one-half of the girder, or 5 in. and 11½ in. to the joist, which is sized down ½ in. on the hanger. The total shrinkable material is 11½ in.+5 in. or 16½ in., or 2½ in. more than at the sill. To equalize this, the end of the joist in the hanger should be sized down 2½ in. more, which, as it has been already sized down

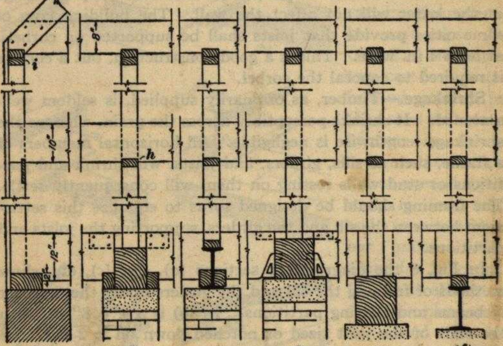



FIG. 8

½ in., will amount to 3 in. To notch the joist to this extent, however, is not to be recommended.

The joists should never rest directly on top of a wooden girder, as shown in (*e*), as the settlement will be due to the shrinkage of the girder plus that of the beam, or say 10 in.+11½ in.=21½ in., or 7½ in. more material than at the sill.

A good arrangement is shown in (*f*), where an I-beam girder has a 2½″×4″ wooden strip resting on its upper flange and upon this the joists are sized down about ½ in. The shrinkable

material is $11\frac{1}{2}$ in. for the joist and $2\frac{1}{2}$ in. for the strip, or 14 in., which is the same as at the sill. The only objection to the girder in (*f*) is that it extends below the cellar ceiling.

The girders in (*b*), (*c*), and (*d*), etc. are shown supporting bearing partitions that hold up the joists of the upper stories. These girders should also be designed so that the settlement of the upper floors shall not be more at the partition than at the outside wall. The second-floor joists at the wall above the sill rest on the ribbon, which is spiked firmly to the studs, hence there is very little chance of settlement at this point except that due to the joists themselves and the sill on the cellar wall. As the joists are 10 in. deep and are sized down on the ribbon 1 in., there is 9 in. of shrinkable material, which added to 4 in. of the sill, gives a total of 13 in.

In (*b*), the bearing partition rests on the wooden girder, which is 10 in. deep. With a partition cap *h*, 2 in. thick, the total shrinkable material at this point will be 9 in. for the joist, 2 in. for partition cap, and 10 in. for the girder, or 21 in. With 13 in. at the wall, the difference is 8 in., hence it is unwise to use a wooden girder, such as shown, to support the partition. By the use of the **I** beam in (*c*), the second floor is subject to the shrinkage of 9 in. for the joist, 2 in. for the partition cap, and 2 in. for the sill laid on top of the girder, or a total of 13 in. This is the same as at the wall, thus providing an equality of settlement throughout the second floor. The use of wooden girders, as in (*d*) and (*e*), produces the same inequalities of shrinkage as in (*b*) and should be avoided.

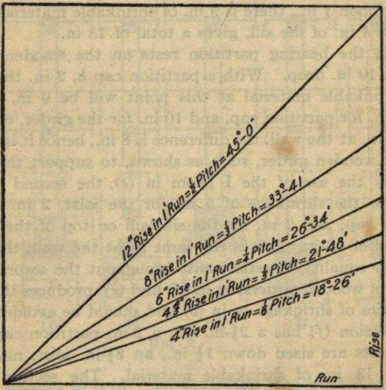
The section (*f*) has a $2\frac{1}{2}$-in. sill, a 2-in. partition cap, and, if the joists are sized down $1\frac{1}{2}$ in., an $8\frac{1}{2}$-in. joist, making a total of 13 in. of shrinkable material. The section in (*c*) with an **I**-beam girder gives the best results.

If there is no unequal settling of the second floor, there will be none in the attic joists. The 4 in. partition cap upon which the attic joists rest will shrink the same as the plate *i*. Where the outer bearings of joists are on masonry walls, the girder, holding up the inner ends and the supporting partitions, should be of steel, or else a brick wall should be used. The use of wood with the grain horizontal should be confined to sills and caps of partitions only.

## ROOF FRAMING

### PITCH OF ROOF

The *pitch of a roof* is the angle of inclination that the roof makes with a horizontal plane. It is described in terms of the ratio of the total rise of the roof to its total span, as $\frac{1}{3}$ pitch, which means that the height of the roof equals one-third of its span; or in terms of its vertical rise in each foot of horizontal run, as 1 in. to the foot or 6 in. to the foot; or by its inclination to the horizontal plane in degrees and minutes, as




45° 0′ or 18° 26′. The accompanying diagram shows several pitches expressed in all three ways.

The pitch of roofs is determined by considerations of appearance, cost, climate, and materials. Where the appearance of the roof is an important feature, as in churches and in buildings designed in certain architectural styles, the roof is made steep and covered with slate, tiles, or shingles; when it is necessary to be economical, the roof is kept flat and covered

with cheaper materials. In climates where there is a great deal of rain and snow, roofs of high pitch are more satisfactory, while in hot and dry climates flat roofs are better. Slate, tiles, and shingles are serviceable only on roofs with a decided pitch. Metal and composition roofs, being watertight, are used for flat roofs.

The accompanying table shows the maximum and minimum pitches allowable for roofs of different materials.

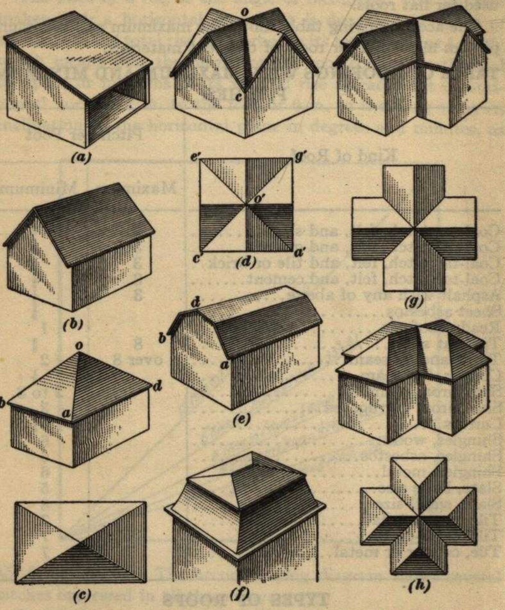
**TABLE OF ROOFINGS WITH MAXIMUM AND MINIMUM PITCHES**

| Kind of Roof | Pitch per Foot | |
|---|---|---|
| | Maximum | Minimum |
| Coal-tar pitch, felt, and slag | 3 | ½ |
| Coal-tar pitch, felt, and gravel | 3 | ½ |
| Coal-tar pitch, felt, and tile or brick | 3 | ½ |
| Coal-tar pitch, felt, and cement | 3 | ½ |
| Asphalt with any of above | 3 | ½ |
| Sheet asbestos | | ½ |
| Ready roofings | | 1 |
| Tin, flat seam | 8 | ⅜ |
| Tin, standing seam | over 8 | 2 |
| Copper, flat seam | | ½ |
| Sheet iron, plain | | 2 to 3 |
| Sheet iron, corrugated | | 3 |
| Canvas | | ¼ |
| Shingles, wood | | 6 |
| Shingles, asbestos | | 6 |
| Shingles, metal | | 6 |
| Slate, large size | | 5 |
| Slate, small size | | 8 |
| Tile, cement, flat | | 7 |
| Tile, terra-cotta | | 7 |
| Tile, copper or metal | | 7 |

## TYPES OF ROOFS

A roof with a pitch or slope of but a few degrees is called a flat roof. In the accompanying figure are shown several types of roofs that are in common use. In (*a*) is a roof with a single slope, which, when the pitch is 30° or more, is called a *single-pitch roof*, a *shed roof* or a *lean-to*. In (*b*) is shown a *double*

*pitch*, or *gable*, *roof*. A *hip roof* is shown in (*c*), where *bo*, *ao*, and *do* are the hips. In (*d*) is a roof with a gable at each of the four sides; the lines where the slopes intersect are called the *valleys*. The valleys are *co* in the perspective view and *o'e'*, *o'c'*, *o'a'*, and *o'g'* on the plan. A *gambrel roof* is shown in




(*e*), the end *abd* is called a gable. A *mansard roof* is shown in (*f*) in which the lower part is almost vertical in its slope and the upper part is similar to a hipped roof; if very flat it is called a *deck roof*. In (*g*) are shown a perspective view and plan of a *gable and valley roof* and in (*h*) a *hip and valley roof*.

## RAFTERS

A *common rafter* is one that extends from the plate to the ridge as *ac′*, Fig. 1. *Hip-and-valley rafters* are placed at the hips and valleys as at *fe′* and *ge′* and at *ki′* and *hi′*. The rafters cut against them are called *jack-rafters* shown at *op*. The *ridge rafter* is placed along the ridge at *c′e′*.

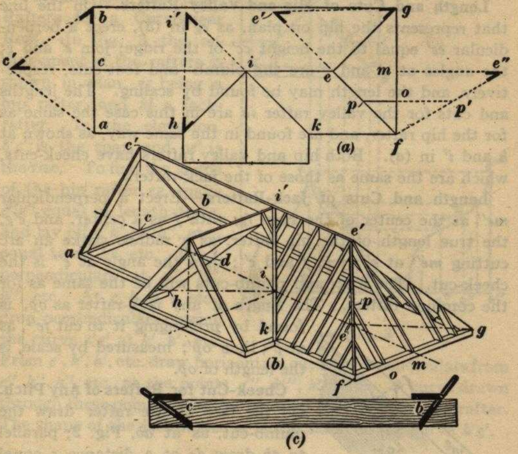



FIG. 1

In roof framing the first step is to lay out a roof plan on a board or sheet of drawing paper, to a scale of, say, 1½ in. to 1 ft., as shown in Fig. 1 (*a*). This figure shows a plan of a roof of uniform pitch, the wing being the same width as the main building. One end of the roof shown is hipped, while the other ends are finished with gables, as may be readily understood by reference to the perspective view (*b*). In both views, the same letters refer to the same parts.

**Length and Cuts of Common Rafters.**—At the center of *a b* in (*a*), erect a perpendicular *cc'* equal to the height of the ridge above the wall plates; join *c'* and *b*; then, the angle at *b* is the foot-cut, and that at *c'*, the plumb-cut of the common rafters. The length may be found by scaling. The angles are transferred to the rafter by means of a bevel as shown in (*c*), in which *b* is the foot-cut, and *c* the plumb-cut.

**Length and Cuts of Hip-and-Valley Rafters.**—On the line that represents the hip on plan, as *eg* in (*a*), erect a perpendicular *ee'* equal to the height *cc'* of the ridge; join *e'* and *g*; the angles at *e'* and *g* are the plumb- and foot-cuts, respectively, and the length may be found by scaling. The lengths and cuts for the valley rafter *ih* are in this case the same as for the hip rafter, and are found in the same way, as shown at *h* and *i'* in (*a*). Both hip and valley rafters have cheek-cuts, which are the same as those of the jack-rafters.

**Length and Cuts of Jack-Rafters.**—Erect a perpendicular *me''* at the center of the span *fg*; with *f* as a center, and *e'g*, the true length of the hip rafter, as a radius, strike an arc cutting *me''* at *e''*; join *f* and *e''*; then the angle at *e''* is the cheek-cut. The foot- and plumb-cuts will be the same as for the common rafters. The length of any jack-rafter as *op*, is found by prolonging it to cut *fe''*, as at *p'*; then *op'*, measured by scale, is the length of *op*.

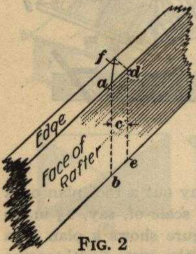


FIG. 2

**Cheek-Cut for Rafters of Any Pitch.** On the face of the rafter draw the plumb-cut, as at *ab*, Fig. 2; parallel to *ab* draw *de* at a distance *c* equal to the thickness of the rafter; square over from *d* to *f*, and join *f* and *a*, thus obtaining the cheek-cut.

**Lengths of Hip or Valley Rafters; Wall Plates at Right Angles.**—Having fixed the rise and run by the square for the common rafter, take 17 in. for the run of the hip or valley rafter. Thus, if the roof is one-third pitch, i.e., 8 in. rise and 12 in. run, the hip or valley rafters will have the same rise, 8 in., and 17 in. run. These results are a trifle large.

**Lengths of Jack-Rafters.**—Having obtained the lengths of the first two adjacent jack-rafters at the toe of the hip rafter, by the graphic or other method, measure the difference between their lengths, and keep adding this difference for the subsequent ones.

**Profiling Hip and Jack-Rafters for a Curvilinear Roof.**—In Fig. 3 the arrangement of the rafters is shown in plan, *eg* being a hip rafter, and *hl* a jack-rafter. In the elevation, $b'c'$ is the span and $oe'$ is the rise. To find the shape of the hip rafter *eg*, make $e''g''$ equal in length to *eg*, and lay off $e''k''$, $k''h''$, etc., equal to *ek*, *kh*, etc. Erect perpendiculars at $e''$, $k''$, $h''$, etc. At *e*, *k*, *h*, *c*, etc., drop perpendiculars cutting the curve $e'g'$ at $k'$, $h'$, etc. From $e'$, $k'$, $h'$, etc. draw horizontals cutting perpendiculars from $e''$, $k''$, $h''$, etc., at the points $e'''$, $k'''$, $h'''$, etc. A curve drawn through these points gives the required outline of the hip rafter. The shape of the jack-rafter *hl* is the same as the curve $h'g'$.

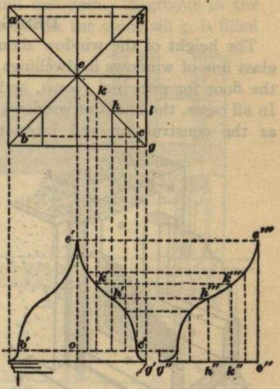


FIG. 3

# WINDOWS

## AREA

The following proportions are given by different authorities for fixing the amount of window surface: (1) One-eighth of the wall surface should be windows. (2) The area of glass should equal at least one-tenth of floor area. (3) One square foot of glass should be allowed to 100 cu. ft. of interior space to be lighted. Class rooms in schools should be provided with a glass area, preferably on the long side of the room, equal

to one-fifth or one-fourth of the floor area of the room. It is better to have a surplus than a deficiency of light, for if too bright, it can be regulated by blinds or shades.

## DESIGN

The height of the window should be twice its width. The glass line of windows in dwellings should be about 30 in. from the floor for principal rooms, and about 36 in. for bedrooms. In all cases, the heads of windows should be as near the ceiling as the construction and interior scheme of treatment will permit, to obtain better light and ventilation. The meeting rails of window sash should be placed not less than 5 ft. 9 in. above the floor; otherwise, the rail will be on a level with the eyes, obstructing the view.

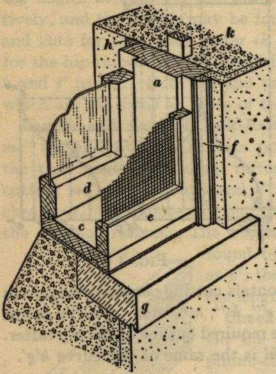


FIG. 1

It is difficult to make sash that are hinged and open inwards water-tight, and those opening outwards are likely to be injured by the action of wind, so that for general service the best results are obtained by use of sliding sash, counterbalanced by means of chords or chains and weights.

Sash stops should be fastened with screws passing through slotted sockets so that they can be adjusted, thus preventing the sashes from rattling.

## CONSTRUCTION

**Cellar Windows.**—For cellar windows, which are often not high enough to permit the use of sliding sash, a single sash hung in a rabbetted frame is used. In Fig. 1 is shown a view and in Fig. 2 a working detail of such a frame in which *a* is the *jamb*, or side; *b* is the *head*, or top; and *c* the *sill*. The head

and jambs are rabbetted to take the sash *d* and a mosquito guard *e*. The *staff bead f* is nailed tightly into the corner formed by the outside of the frame and the masonry jambs, to prevent the entrance of wind and rain. A groove in the underside of the sill, where it rests on the stone sill *g*, is filled with mortar when the window frame is set, thus preventing the passage of air and water. The interior finish is generally omitted in cellar windows, but a simple molding *h* is sometimes nailed in the corner. The frame is shown in a concrete wall and the strips *k* are nailed to the jambs to prevent the frame from slipping out.

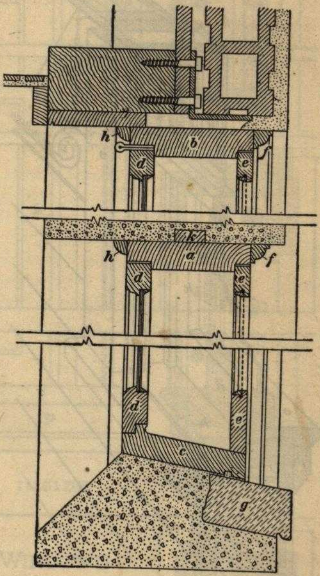



FIG. 2

**Double-Hung Windows.**—In Fig. 3 is shown a view of a window frame with sliding sash, for a frame building. In Fig. 4 is shown a working detail of the same. Windows of this type are known as *double-hung windows*. The pulley stile *a* may be from $1\frac{1}{8}$ to $1\frac{3}{8}$ in. thick, and should be tongued into the blind stop *b* which is $\frac{7}{8}$ in. thick. These tongues make the stiles rigid, preventing them from deflecting sidewise when the sashes are being operated, and form an excellent stop for wind and rain. An open space of from 2 in. to $2\frac{1}{2}$ in. is left between the back of the

pulley stile and the rough stud, thus forming a box for the weights.

A movable pocket for the insertion of the weights is cut out of the lower portion of each pulley stile on the inside so that it may be covered by the lower sash. The parting strip *d* is $\frac{1}{2}$ in. or $\frac{5}{8}$ in. thick, and passes into a groove $\frac{3}{8}$ in. deep in the pulley stile. The outside casing, or *architrave*, *e*, $1\frac{1}{8}$ in. thick $\times$ 5 in. wide, is firmly nailed through the blind stop into the pulley stile and to the wall sheathing. The inner face of the window frame is finished with a casing, or architrave, the width being sufficient to cover the plaster joint. The sash stop *g*, from $\frac{1}{2}$ in. to $\frac{5}{8}$ in. thick, is secured with round-headed screws passing through slotted sockets for adjustment. This member should not be less than $1\frac{1}{2}$ in. in width to take the window shade properly. The members *g*, *d*, and *b* should be kept in line, their projection beyond the face of the pulley stile being regulated by the thickness of the sash stop.

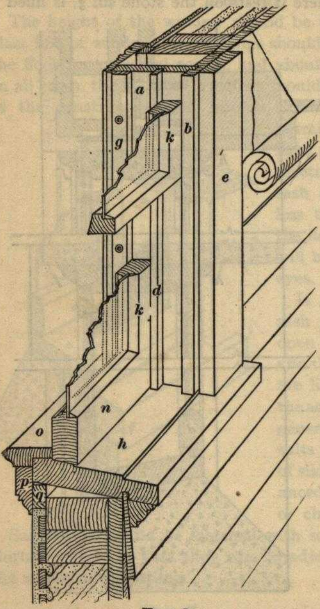


FIG. 3

The sill *h* is made of 2-in. stock. The bevel formed on the inside of the lower sash and on the corresponding part of

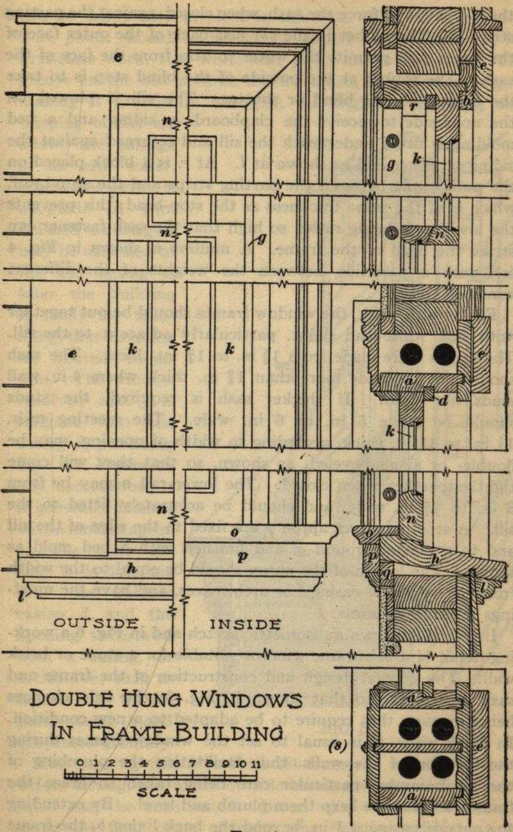

OUTSIDE
INSIDE
DOUBLE HUNG WINDOWS
IN FRAME BUILDING
(8)
0 1 2 3 4 5 6 7 8 9 10 11
SCALE

FIG. 4

the sill, tends to force the sash, when closed, against the parting strip *d*. The rabbet in the sill just back of the outer face of the lower sash permits the water to drip from the face of the sash. The rabbet at the outside of the blind stop is to take the bottom of the blind or shutter. The sill is plowed on the underside to receive the clapboards or siding and a bed molding is fitted underneath the sill and returned against the siding at either end as shown at *l*. At *r*, is a block placed on the pulley stile between the parting strips and the stop-bead, which is of the same thickness as the stop-bead; this prevents the lower sash being raised so high that the sash fastener can strike the head of the frame. A mullion is shown in Fig. 4 (*s*), with a partition between the weights of the different windows.

For durable work, the window frames should be put together with stiff white-lead paint, particularly adjacent to the sill. The sashes *k* are made from $1\frac{1}{8}$ in. to $1\frac{3}{4}$ in. thick. The sash should not be made more than $1\frac{3}{8}$ in. thick where 4-in. wall studs are used. If thicker sash is required, the studs should be made 5 in. or 6 in. wide. The meeting rails, $1\frac{1}{8}$ in. to $1\frac{3}{8}$ in. thick, according to width of opening, may be double- or single-beveled, as shown, so that they will come tightly together when closed. The lower rail *n* may be from 3 in. to $4\frac{1}{2}$ in. wide, and should be accurately fitted to the sill. A stool *o* and an apron *p* are fixed to the edge of the sill and to a plaster ground *q*, and finished with a bed mold as shown. The length of the apron should be equal to the width from out to out of casings, or architraves, and have the moldings returned on same.

In Fig. 5 is shown an isometric sketch and in Fig. 6 a working detail of a box-frame window suitable for a stone or brick wall. The general design and construction of the frame and sash are similar to that shown in Fig. 3; the only changes being in parts that require to be adapted to a new condition. In brick walls, it is usual to set the window frames during the erection of the walls, thus facilitating the plumbing of the brick jambs, particular care being taken to brace the frames, in order to keep them plumb and level. By extending the outside casing *a* 1 in. beyond the back lining *b*, the frame

can be firmly held in place in the wall. The sill *c*, made of 2-in. plank should be bedded in haired lime mortar, or, for first-class work, stiff white-lead paint and white sand. The groove on the bed permits the formation of a mortar tongue, making it practically air-tight; the slightest shrinking and warping of the sill allows the passage of air and water, unless this device is adopted. A $\frac{7}{8}$-in. finished casing *d* may be attached to the box casing *e*, after the building is ready for trimming, thus covering its marred condition. The window stool or seat *f* is tongued into the casing *d*, providing for its expansion and contraction; it is generally finished with a molded apron *g*. The jamb casing *h* is tongued into the finished casing *d*, and the opening trimmed with a casing, or architrave, such as *i*, nailed to the jamb casing *h* and the plaster ground *j*.

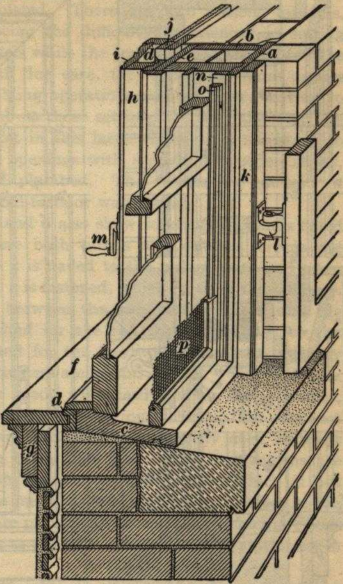
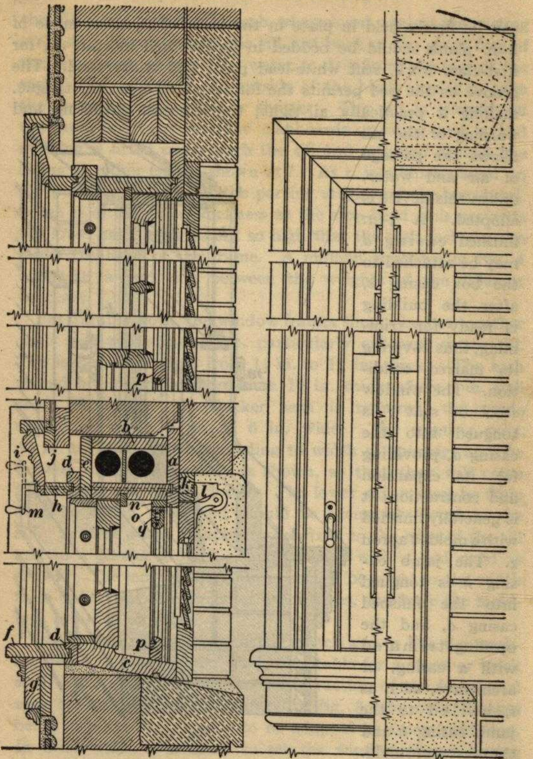


FIG. 5

The hanging stile *k* in brick-set frames is attached thereto before setting, but where outside blinds are not used, an angle mold may be substituted. Before the window frames are given the final coats of paint, the hanging stiles may be




DOUBLE HUNG WINDOWS IN BRICK BUILDING

FIG. 6

removed and the joint between the frame and the brickwork calked with oakum to make a weather-proof joint, after which the hanging stiles are replaced.

In stone walls, window frames are not usually set until the building is roofed and is prepared for the plastering, or has the plastering completed. There are two reasons for this, the principal one being the difficulty experienced in setting jamb stones and lintels while the frame is in position, and the second that, with all due care, the frames are more or less damaged during building operations and are never so true to line, level, and plumb as those set in place after the walls are completed. When set in this latter order, it is necessary to encase the masonry openings with screeds or wooden strips, carefully alined and plumbed. The frames are secured in place by means of hold-fasts or wall plugs.

**Screens.**—Figs. 5 and 6 also show screens and blinds fitted to the frame. Where both blinds and outside screens are used, a special piece *n* is nailed to the pulley stiles and upon this a strip, or track, *o* is fastened, which receives the screen *p*. Space must be left between the face of the screen and the inside face of the blind for the rod that is fastened to the slats in the blind, and for the hardware where the ordinary blind fasteners or adjusters are used.

The screens *p* are made with hardwood or metal frames, with a wire mesh stretched tightly over them. The cheapest screens have steel-wire mesh and consequently need frequent painting to preserve them from rust. The best screens are covered with a mesh made of copper bronze, which is not subject to rust. The mesh is made with 14 to 16 wires to the inch. The screens are provided with springs *q*, which are concealed in the grooves at the sides, and will remain stationary in any position.

**Blinds and Shutters.**—*Blinds* are made with slats, either fixed or movable; *shutters* are solid and generally paneled. Both blinds and shutters are generally made 1⅛ in. in thickness and are hung on L-shaped hinges, which allow of their clearing a reveal, or an outside architrave, and lying flat against the wall of the house. They are secured by blind fasteners or by blind adjusters. Devices are made that enable a person to

open or close the blinds or shutters from within the house, without the necessity of opening the window, and which hold the blind firmly in any desired position. A device of this kind is shown at *l* and *m*. The box *l* contains a worm-gear that is operated by turning the crank *m*, thus opening or closing the blind.

**Storm Sash.**—Storm sash are sometimes provided for windows and are made generally of $1\frac{1}{8}$ in. thick material and are hung in the rabbet that is occupied by the blinds when closed. The blinds are either removed or left open while the storm sash are in place.

**Casement Windows.**—Casement windows are those that have sashes hinged at the sides and swinging in or out like doors. *French windows* are casement windows, having two sashes with meeting stiles down the center. They are generally carried down to the floor and are high enough to be used as doors. Casement and French windows are difficult to construct so that rain will not beat in, but as they are very effective from the standpoint of design, different devices have been tried to make them serviceable. A fairly satisfactory detail of a French window is shown in Figs. 7 and 8, showing the most effective treatment of the sill and jamb, which are the weak features of these windows. The sill should be made of $2\frac{1}{2}$-in. material and rabbeted and the surface curved as shown at *b*.

This feature intercepts rain that is blown against the joint of the sash and the sill. If, however, water should be forced into the joint it would fall into a gutter, *d*, which is plowed in the sill and which is drained, in turn, through the holes *c*, which are about $\frac{3}{8}$ in. in diameter and about 2 ft. apart. The drip mold *a* on the bottom rail of the sash also aids in stopping rain that may be blown against the bottom joint and forms a drip for water that washes down the face of the sash. The jambs instead of having straight rabbets, like those of a door, have semi-circular channels worked into them, as shown at *e*, into which a half-round projection on the stile of the sash works. The meeting stiles are designed with beveled rabbets, so that one sash can be opened at a time. *Astragals g*, are placed on the outside and the inside so that both shall be on

the center. The inside astragal, if the window is to be fitted with Cremone or Espagnolette bolts should have a flat surface, $1\frac{3}{4}$ in. in width, to receive them.

The sash in casement windows should be made thicker than are used for double-hung sash, as there is more strain upon them due to their being hung on one side. For small casements, $1\frac{3}{4}$ in. is a sufficient thickness and $2\frac{1}{4}$ in. or more for large sash.

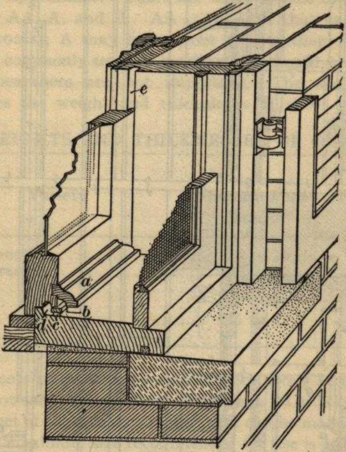
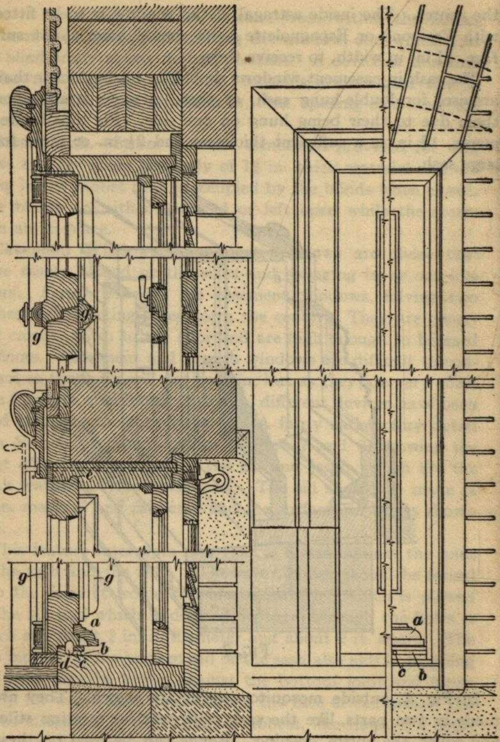



FIG. 7

In Fig. 7, outside mosquito screens are shown. They are made in two parts, like the sash, with vertical meeting stiles and cover the entire opening. Blinds can be used on these windows if shutter workers are provided as shown.

**Weather Strips.**—Weather strips are made of rubber strips mounted on wooden moldings, but as the rubber soon becomes hard and brittle these are not to be recommended. The best




FRENCH WINDOWS IN BRICK BUILDING

0 1 2 3 4 5 6 7 8 9 10 11
SCALE

FIG. 8

kinds of weather strips are made of strips of a non-corrosive metal and fitted to the sash so as to keep out wind and rain. There are several makes of these strips all of which have merit.

## GLASS

**Sheet Glass.**—Common window glass is technically known as *sheet*, or *cylinder, glass* because it is first blown in the form of a cylinder, then cut and flattened out. It has a more or less wavy appearance. There are three grades of sheet glass known as AA, A, and B. AA is the best that can be made by the process; A may have more defects than AA, and is the grade commonly used in buildings; B should be used only when appearances are not important. The accompanying table gives the weight and thicknesses of sheet glass. The

**WEIGHTS AND THICKNESSES OF GLASS**

| Variety | Weight per Square Foot Ounces | Thickness Inch |
|---|---|---|
| Single strength | 14 to 16 | $\frac{1}{13}$ |
| Double strength | 19 to 21 | $\frac{1}{8}$ |
| 26-oz | 25 to 27 | $\frac{2}{15}$ |
| 32-oz | 31 to 33 | $\frac{1}{7}$ |
| 36-oz | 35 to 37 | $\frac{1}{6}$ |

largest sheets made of single strength are about 34 in. × 50 in., but it is not safe to use a sheet larger than 20 in. × 24 in. The largest sheet of the double strength that can be made is 60 in. × 70 in., the maximum size recommended for use is 40 in. × 44 in.

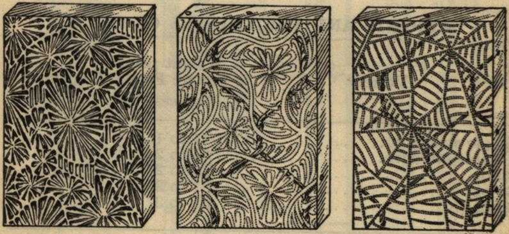
**Special Sheet Glass.**—There are special grades of sheet glass, known as *crystal sheet*, weighing 26, 32, and 36 oz. per sq. ft. which are of better quality and can be had in larger sheets. They are designed for use where the common sheet glass is not good enough and where a glass cheaper than plate glass is required.

**Plate Glass.**—Plate glass is made by rolling the melted glass on a table to an approximately even thickness and then giving the surfaces a high polish. The greatest width that can be

rolled is 164 in. and the greatest length 260 in. A plate with an area of about 240 sq. ft. is about as large as can be made economically. The thickness varies from $\frac{7}{32}$ in. to $\frac{5}{16}$ in. Plates more than 75 sq. ft. in area should be at least $\frac{1}{4}$ in. thick. Plates over 100 sq. ft. in area should be $\frac{1}{4}$ in. full. Plate glass is also made of greater thickness for special purposes.

Polished plate is graded as *glazing quality*, which may contain small bubbles, fine scratchings, etc.; *selected glazing*, which is almost free from defects and is used in high-class residences, show-cases, etc.; and *silvering quality*, which is as near perfect as possible and is used for making mirrors.

**Mirrors.**—Mirrors are made by two processes. The *patent back* is formed by treating the glass with two coats of nitrate



(a) (b) (c)

of silver, then varnishing and painting. This kind of mirror will last about 10 or 12 yr. The old process consists of placing a layer of tin-foil upon a table, and upon this a thin film of mercury upon which the plate of glass is floated, and then pressed down by weights. The result is a permanent back.

This method is not used much at the present time as it is more expensive and the process of manufacture is deleterious to the health of the workmen.

**Figured Rolled Glass.**—Rolled glass is made with figured or patterned surfaces that make it translucent, but in many cases causes a better transmission of light than plain glass. This glass is made in various patterns called *Florentine*, *maze*,

*cobweb*, etc., which are shown in (*a*), (*b*), and (*c*) of the accompanying figure.

**Wire Glass.**—Wire glass has a wire mesh embedded in the body of the glass, as illustrated in (*b*) and (*c*). This product has a great value as a fire-retarding material. Even when the glass is cracked by intense heat, the fragments are held in place by the wire that it protects. It is furnished either clear or with a figured surface as shown.

**Prism Glass.**—Prism glass is designed to deflect rays of light and direct them into rooms and buildings that do not obtain sufficient light through plain glass. It is generally made so that the prisms project from the inside or underside of the sheet while the other side has a plain surface.

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## OUTSIDE FINISH

**Water-Table.**—Before the siding is put on the sheathed frame of a wooden building, a water-table *de*, Fig. 1, is placed all around the structure, with its lower edge extending about 1 in. below the sill. The water-table has the drip mold *d* as its top member, and this has a tongue *f* extending up behind the siding. The water-table serves the purpose of shedding the water that runs down the side of the house, away from the foundation walls.

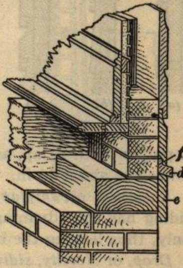


FIG. 1

**Sheathing Paper.**—One or more thicknesses of heavy felt or resinous building paper are laid over the sheathing, and serve to prevent drafts from penetrating the walls, also to prevent the transmission of heat. Strips of this paper or felt are tacked to the backs of corner boards, window and door frames, pilasters, etc., before fastening them in place.

**Corner Boards.**—Corner boards are used where a building is covered with siding. Where shingles are used in place of

siding corner boards are frequently omitted. Corner boards consist of two strips of board put together so as to form an angle and are nailed to all the corners of the building and the siding is cut to fit in tightly between them. Pilasters are sometimes used in place of corner boards.

**Siding.**—When the water-table and corner boards are in place and the window and door frames are set, the siding is put on in horizontal courses over the paper. It is nailed through its lower edge into the sheathing and the nails are set, or driven so that the heads are slightly below the surface of the boards. After the boarding receives its first coat of paint these holes are filled with putty and the nails concealed and protected. The best woods to use for siding are white pine, cypress, and redwood. Yellow pine is also used but requires special care in painting.

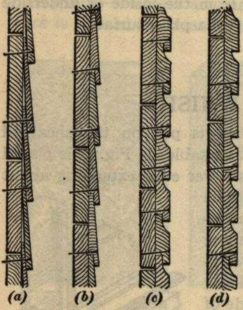


FIG. 2

*Beveled siding*, shown in Fig. 2 (*a*), consists of sawed and planed boards about 16 ft. long. It is manufactured in 4 in., 5 in. and 6 in. widths, is $\frac{5}{8}$ in. thick at the bottom edge and about $\frac{1}{4}$ in. thick at the upper edge. This siding is put on with a lap, as shown, the upper board covering the lower one about $1\frac{1}{4}$ in.

*Rabbetted*, or, *shiplap, beveled siding* is shown in (*b*). This siding has the advantage that the nails go through one edge only, thus leaving the board free to expand and contract.

*Drop*, or *Novelty, siding*, shown in (*c*) and (*d*), has a uniform thickness of $\frac{3}{4}$ in. to $\frac{7}{8}$ in. and a width of $5\frac{1}{2}$ in. In very cheap work the siding shown in (*d*) is used, which has a groove worked in the middle of the face in imitation of a joint.

**Shingling.**—Shingles are used to cover the outside walls of wooden houses. They give a less formal effect than siding and are capable of various effects, which are produced by the

use of fancy butts and by staining the shingles. A shingled wall is slightly more expensive than one covered with siding, but it generally forms a more weather-proof covering.

**Veneered Buildings.**—Frame buildings are often veneered with a 4-in. wall of brickwork as shown in Fig. 3 (*a*), (*b*), and

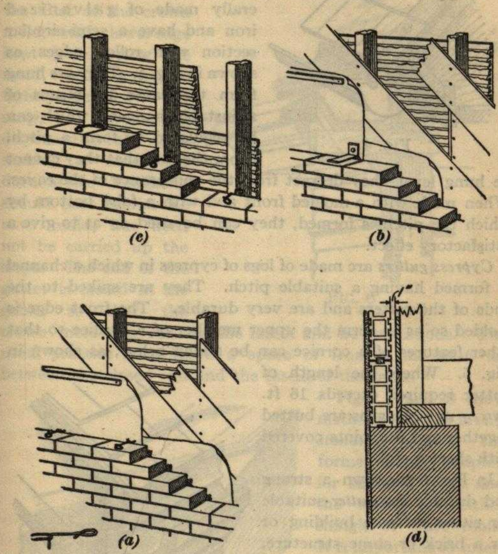



FIG. 3

(*c*), or with a 3-in. or 4-in. wall of terra-cotta blocks which may be stuccoed, as shown in (*d*). In such cases, the frame of the building should be set back from the face of the foundation wall as shown in (*d*). An air space of 1 in. should be left between the masonry veneering and the sheathing boards. Anchors are used as shown to tie these veneering walls to the

studs or sheathing boards. Sheathing paper applied to the boarding, as shown an (*a*) and (*b*), adds greatly to the comfort of the house.

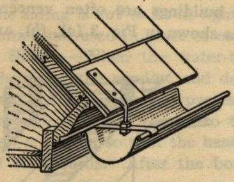


FIG. 4

**Eaves and Gutters.**—*Metal gutters*, or *eaves troughs*, are generally made of galvanized iron and have a semi-circular section with rolled edges as shown in Fig. 4. They are hung from the eaves by means of adjustable hangers, which can be regulated to form a pitch. From the fact that they cannot be hung level, they detract from the appearance of the eaves. When made with a molded front and with a false bottom by which the pitch is formed, they can be used so as to give a satisfactory effect.

*Cypress gutters* are made of logs of cypress in which a channel is formed having a suitable pitch. They are spiked to the ends of the rafters and are very durable. The front edge is molded so as to form the upper member of a cornice so that other features of a cornice can be added below, as shown in Fig. 5. Where the length of gutter required exceeds 16 ft. two or more lengths are butted together and the joints covered with sheet metal.

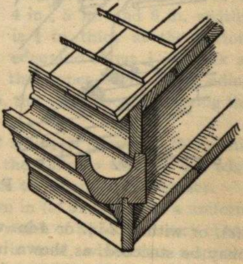


FIG. 5

In Fig. 6 is shown a strong and durable *box gutter* suitable for either a frame building or for a brick or stone structure, having a wooden cornice. A series of lookouts are nailed to the wall studs (or built into the brickwork or stonework), forming a solid base for the cornice and gutter. The width of the lookouts may be varied, to obtain the grade for the gutter bed, or it may be uniform, strips being nailed to the

upper edges of the pieces. On a gable roof, the cover-plate over the crown mold should be kept in line with the sheathing on the roof slope. In lining this gutter, if a strip of hoop iron is tacked to the fillet of the crown mold, with its lower edge kept ¼ in. below the mold, the lining may be tightly clasped over the strip, and face-nailing dispensed with, thus making a neat and durable job. The lining should pass behind the eave mold, but need not be carried up the slope. The end of the gutter is closed at the gable, so that the crown mold can run up the fascia and be continuous. The usual practice is to leave a space of from 4 in. to 6 in. between the closed end and the fascia of the gable.

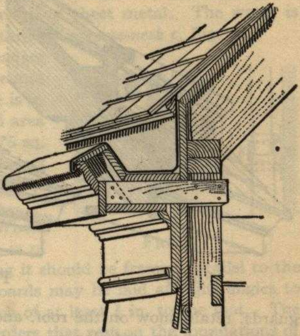


FIG. 6

Figs. 7 and 8 show methods of forming *standing gutters*, the former being adapted for shingled roofs, and the latter for either shingle or slate roofs. It is important to insert the tilting fillet in both cases, for two reasons: (1) To obtain the tilt for the lower double course so that the bed of the second course will lie close to the back of the lower course; (2) to form a drip at the edge of the lower course, so that water will not

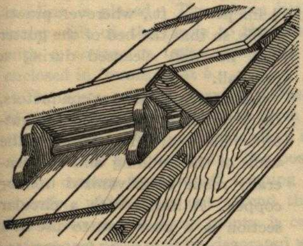


FIG. 7

be drawn up by capillary attraction under the shingle or slate and pass over the upper edge of the flashing. These are durable forms of gutters, but they have the disadvantage of acting as

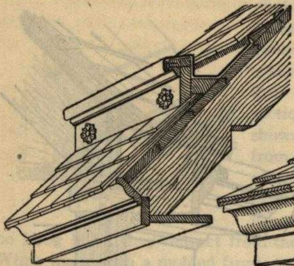


FIG. 8

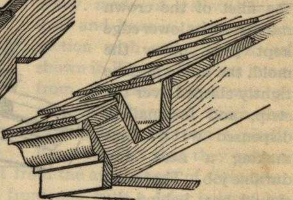


FIG. 9

guards, retain snow on the roof, and mar to some extent the appearance of the roof planes.

*Sunk gutters* are built below the plane of the roof and must be lined with sheet metal. They should be closed at the ends so that the crown mold can be run up the gables, as shown in Fig. 9. Gutters should have a pitch of $\frac{1}{8}$ in. per lin. ft., wherever practicable, so that the bed of the gutter will be well cleansed during a rain fall.

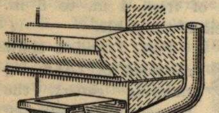


FIG. 10

**Leaders.**—Leaders or conductors, carry the water away from the gutters. They are hung against the walls of the building and are generally made of galvanized iron or copper. A leader with a circular section is a poor one to use in a climate where severe freezing occurs. It is apt to be filled with ice and burst as its circular section does not permit of its yielding. A leader with a corrugated or rectangular

section yields to pressure by changing its shape, thus avoiding rupture.

Leaders are often provided with ornamental *heads, a* Fig. 10, and *bands, b*, Fig. 11, formed of sheet metal. The water is conveyed into the leader through a *goose-neck c*, Fig. 10.

The proper sizes of leaders will vary with the climate and the rain fall. A safe rule is to allow 1 sq. in. of sectional area of leader pipe for every 75 sq. ft. of flat roof area. No leaders should be less than 2 in. in diameter.

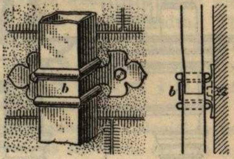



FIG. 11

**Porches and Piazzas.**—Where the floor of the piazza is of wood, the joists supporting it should be framed parallel to the house so that the floor boards may be laid at right angles to the house and have a pitch of at least $\frac{1}{8}$ in. to the foot. The joists are supported on girders that rest on the foundations of the house and upon piers of brickwork or stonework under the front of the piazza. A fascia *a*, Fig. 12, is carried around the front of the piazza covering the floor framing. The edge of the floor extends over this fascia and is finished with a semicircular profile, called a *nosing*, under which a *cove* or other molding is placed. The spaces between the piers from the under side of the fascia to the ground are usually filled in with a *screen*, or *lattice*, generally formed of wooden strips enclosed in frames as at *b*.

The *posts, columns, cornices, balustrades*, and other features of the piazza depend for their form on the style of design of the building. When a Gothic effect is desired details like those shown in (*a*) may be used. The posts may be square and the sharp corners beveled off forming *chamfers*, as at *c*. This chamfer, which does not extend the full length of the post but is stopped at given points, is called a *stop-chamfer*. The rafters and plate may be decorated with stop-chamfers and the ends of the rafters may have scroll-sawed ends, as at *d*. The roof boards are shown nailed to the tops of the rafters with the face side down. They should be thick enough to take

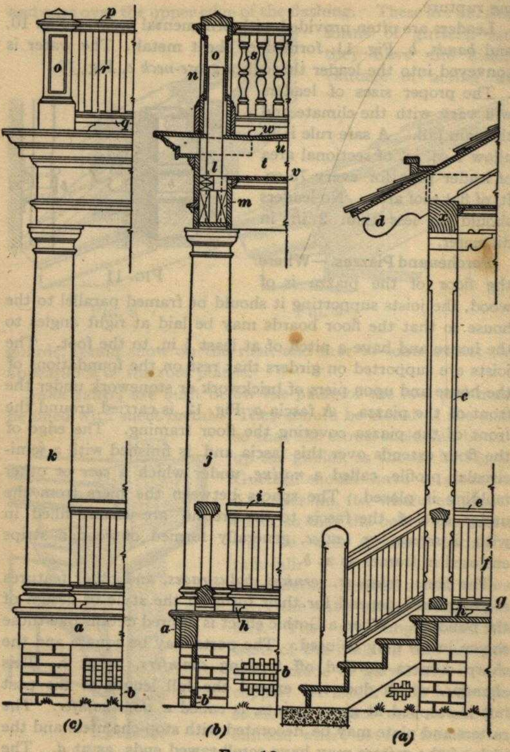



FIG. 12

the nails that hold the roofing material, which is nailed directly to the roofing boards, and not have the points of the nails come through the exposed face.

The *railing* consists of the *top rail e*, the *bottom rail g*, and the *balusters f*. The rails are designed with a slight wash or slope on the upper surfaces. Top rails are sometimes made wide enough to form a shelf or seat 6 in. or 8 in. in width. The bottom rail where the posts or columns of the piazza are far apart should be supported on blocks *h* resting on the floor. For ordinary buildings, stick balusters made of ⅞ in. stuff, 1¼ in. or 1⅜ in. wide, are frequently used.

In buildings designed in the Renaissance or Colonial styles, columns and entablatures are used, as shown in (*b*) and (*c*). The flat roof shown is formed by the roof beams or rafters *t*,

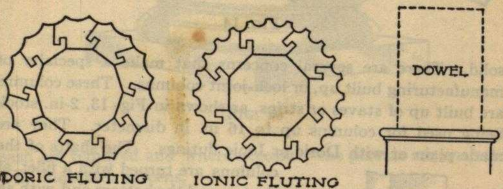


FIG. 13

which extend from the house to the plate *l* which rests on the girders *m*. The girders are supported on the *dowels* on the columns, shown in Fig. 13. The boarding *w* Fig. 12, is nailed on top of the rafters, upon which furring *u* is first nailed to form the pitch, and ceiling boards *v* ⅞ in. thick, are nailed on the underside to form a finished ceiling. The entablature is formed as shown and supported by the necessary blocking or furring.

A *balustrade n* is frequently built around the roof of the piazza with newels *o*, top rail *p*, bottom rail *q*, and either stick balusters *r*, or turned balusters *s*. The juncture of the newels with the roof should be carefully flashed.

The *columns* *j* and *k*, are generally built up, when more than 6 in. in diameter, as they are liable to check or crack if made

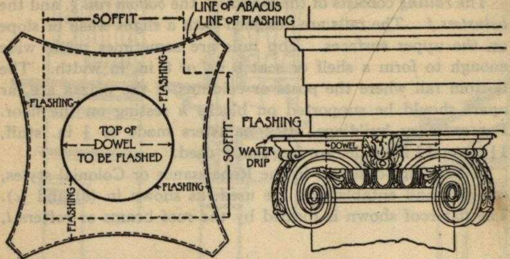



FIG. 14

solid. There are several concerns that make a specialty of manufacturing built up, or lock-joint columns. These columns are built up of staves or strips, as shown in Fig. 13, 2-in. stock being used for columns up to 16 in. in diameter. They are made plain or with Doric or Ionic flutings. The shafts of the columns are turned with a fillet at the top and the bottom and with an *entasis*, or swelling characteristic to the order. The columns are fitted with wood or composition *capitals*, Fig. 14, which fit around the dowels. Upon the dowels, the roof structure of the porch is supported. Composition capitals are generally made of a fibrous composition that will stand the effects of weather better than wood. The tops of capitals, however, should always be well flashed.

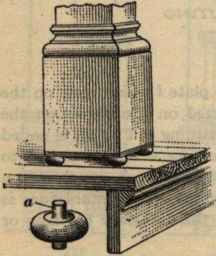



FIG. 15

The bases of columns and posts resting upon the floor of the porch will, in time, decay on account of moisture finding

its way beneath them. A device for avoiding this result is shown in Fig. 15. It consists of four metal buttons, *a*, with dowels, that are let into the under side of the base and into the floor, and keep the base free from the floor. Another method is to make the square part of the base of metal as shown in Fig. 16.

Where the floor of a porch or piazza is close to the ground, it is often made of masonry and finished with cement, brick, or tiles.

Piazzas are often enclosed with sash and used as sun rooms, and are sometimes provided with fireplaces. In summer, the

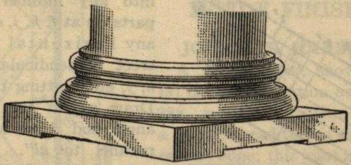


FIG. 16

sash are removed and where necessary the piazzas are enclosed with mosquito screens.

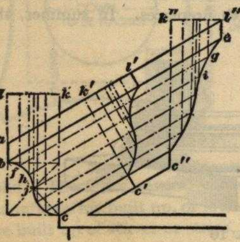
**Flagpoles.**—For a flagpole extending from 30 to 60 ft. above the roof, the following proportions give satisfactory results: The diameter at the roof should be made $\frac{1}{50}$ the height above the roof, and the top diameter $\frac{1}{2}$ the lower. To profile the pole, divide the height into quarters; make the diameter at the first quarter $\frac{15}{16}$; at the second quarter, $\frac{7}{8}$; and at the third quarter, $\frac{3}{4}$ of the lower diameter. Thus, if a pole is 41 ft. 8 in. high above a roof, the lower diameter is $\frac{1}{50}$ of 41 ft. 8 in., or 10 in.; that of the first quarter, $9\frac{3}{8}$ in.; the second, $8\frac{3}{4}$ in.; the third, $7\frac{1}{2}$ in.; and the top, 5 in.

Flagpoles may be made of spruce or pine; Oregon pine is preferable, and where the entire sap-wood is removed by cutting the pole out of the heart of a large trunk, a durable pole is obtained. The pole should be painted with at least four coats of white lead, and should be capped by a suitable

finial, terminating in a gilded ball. Halyards should be at least ½ in. in diameter, and be of waterproofed, braided cotton, or Italian hemp.

## DEVELOPMENT OF A RAKING MOLD

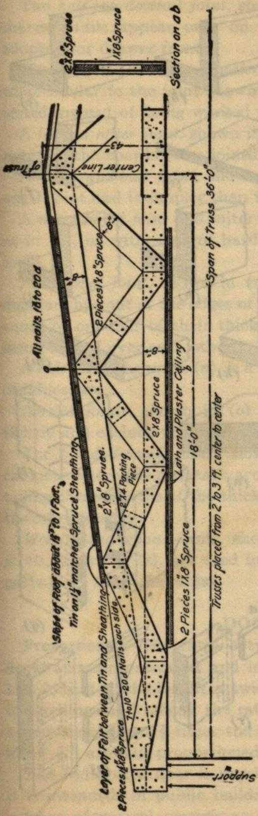
In the accompanying illustration is shown a method for determining the cross-section of a raking mold to miter with a given eave mold. This method will apply equally well to any molding. The eave mold in this case is a cyma recta, the profile being shown as *abfhjc*. Divide the outline into any number of equal parts, as at *f*, *h*, *j*, etc. Draw any horizontal line *lk* and erect perpendiculars from *f*, *h*, *j*, etc., cutting the line *lk*. Draw $al''$ at the required angle and draw *be*, *fg*, etc., parallel to $al''$. From any point $l'$, lay off the distance $l'k'$ and subdivisions equal to *lk*. Drop perpendiculars to $al''$ from $l'$, $k'$, etc. intersecting *be*, *fg*, etc. Through the intersections thus found, trace the line $l'c'$, which is the profile of the required mold.




To find the profile of a vertical cut in the raking mold, at any point, as $l''$, lay off $l''k''$ equal and parallel to *l k* and having the same subdivisions. Proceed to find points *e*, *g*, *i*, $c''$, etc., as before.

## PLANK TRUSS

The accompanying illustration shows a trussed rafter suitable for a flat pitch roof of from 30 to 40 ft. span, the rafters being set at from 2-ft. to 3-ft. centers. The rafters and joists are 2 in.×8 in., and of a good quality of spruce or hemlock. The lattice braces are 1 in.×8 in., and are placed in pairs, one on each side of the main members, to which they are spiked. The spiking should be well done, especially near the supports. The tie-member is spliced at the center of the span by two




1″×8″ fish-plates, well spiked to the ceiling joist; two iron dogs, well driven in, further strengthen the splice. The roof is covered with 1¼″×6″ tongued-and-grooved surfaced spruce, then with a layer of felt upon which tin is laid. All other necessary details of construction are shown.

# INSIDE FINISH

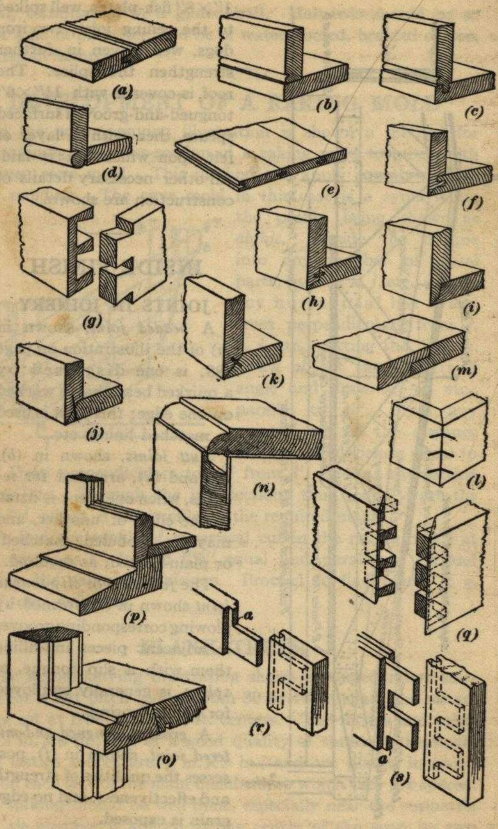
## JOINTS IN JOINERY

A *beaded joint*, shown in (*a*) of the illustration on page 288, is one disguised by a quirked bead that is worked on one edge; this joint is used in matched lining, etc.

*Butt joints*, shown in (*b*), (*c*), and (*d*), are used for returns, when one piece is fitted to the edge of another, and may be rabbeted, matched, or plain-butted, as required.

The *feathered* or *slip-tongue joint* shown in (*e*), formed by plowing corresponding grooves in adjacent pieces and filling them with a slip tongue, or *spline*, is generally employed for plank flooring.

A *grooved, tongued-and-mitered joint*, shown in (*f*), possesses the qualities of strength and effectiveness, and no edge grain is exposed.


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(k)
(m)
(j)
(n)
(l)
(p)
(q)
a
(r)
(o)
a'
(s)

The *half-lap dovetail joint*, shown in (*g*), is a form in which the dovetails appear only on one side, and is the method adopted for drawer fronts.

The *lapped-and-tongued miter joint*, shown in (*h*), is somewhat similar to the joint shown in (*f*), but a slip tongue is inserted instead of being worked out of the solid material.

A *lapped miter joint*, shown in (*i*), is made by rabbeting and mitering the boards to be joined, and securing them with nails.

A *miter-and-butt joint*, shown in (*j*), is a good form for an angle joint and is simpler than the joint shown in (*i*).

A *miter-keyed joint* is a miter strengthened by a slip feather, as in (*k*), or with slips of hardwood fitted into saw kerfs, as in (*l*).

A *rabbeted joint*, shown in (*m*), is formed by cutting rectangular slips out of the edges of the boards to a depth generally equal to one-half of their thickness, the tongues thus formed being lapped over each other.

A *rule joint*, shown in (*n*), is a hinged joint used for the leaves of tables, etc.

*Beveled joints*, shown in (*o*) and (*p*), are formed to close tightly and exclude the wind and water.

The *blind dovetail joint*, shown in (*q*), used for boxes and cabinets where the dovetails are not to show, is made by dovetailing three-fourths of the thickness of the board and mitering the other fourth.

*Mortise-and-tenon joints*, shown in (*r*), and *double-tenoned joints*, shown in (*s*), are used in framing doors together. The parts *a* are called *haunches*.

## DOORS

**Proportions.**—The ratio between the width and height of doors at main entrances and in public buildings is usually as 1 to 2; that is, the height is twice the width. For single doors in dwellings and offices, the ratio should be as 1 to $2\frac{1}{2}$; or the height should be $2\frac{1}{2}$ times the width; doors $2' 8'' \times 6' 8''$ and $3' \times 7' 6''$, are thus proportioned.

The width of a door is regulated by the purpose for which it is intended: in public buildings, provision is made for the passage of several persons at a time; in private houses and

offices, a width suitable for one person is sufficient. In the former case, the width may be from 6 to 14 ft., while in the latter, the general rule makes the minimum width 2 ft. 8 in. for communicating doors, and 2 ft. for closet doors. A hinged door more than 4 ft. wide should be made double; that is, in two folds. As double folding doors take up considerable wall space when kept open, sliding doors are frequently substituted. Where there are several doors of different widths in the same room, to give a better effect to the interior treatment the height of the principal doors should be fixed by the proportion given, and the others made the same height. If the width of double or sliding doors does not exceed 6 ft., the height may be that of principal doors, but if wider, the height should be one-fourth more than the width. The width of sliding doors, however, is largely regulated by the depth obtainable for the pocket in the partition.

The width of the stiles and top rail should be about one-seventh the width of the door, the bottom rail about one-tenth the height, and the muntins and lock-rails $\frac{1}{2}$ in. less in width than the stiles. The thickness will depend somewhat on the size, style of finish, and the class of lock to be used. If the door framing is solid and rim locks are used, the thickness for chamber doors may be $1\frac{1}{4}$ in.; if mortise locks are used, the thickness should not be less than $1\frac{1}{2}$ in. Solid doors for principal rooms are made from $1\frac{3}{4}$ in. to 2 in., and entrance and vestibule doors from $2\frac{1}{4}$ in. to $2\frac{1}{2}$ in. thick. When doors are veneered, the thickness is usually increased $\frac{1}{4}$ in.

When mortise locks are used, the doors should, for strength, be framed with a lock-panel so that the joints adjacent to the lock will not be injured.

**Construction.**—The mode of constructing a five-paneled *solid door* is shown in Fig. 1, the moldings and certain parts being removed to show clearly the joints. The parts marked *a* are the outer stiles; *b*, the muntins; *c*, the bottom rail; *d*, the lock-rails; *e*, the top rail; *f*, the lower panels; *g*, the lock-panel, and *h*, the upper panels. The mortises *i* are made one-third the thickness of the framing into which the tenons *j* are fitted. The edges of the framing are grooved $\frac{1}{2}$ in. deep, to receive the panels, the width of the groove being the same as the

thickness of the tenon. The upper edge of the tenons of the top rail and the lower edge of the tenons of the bottom rail are haunched, as shown at *k*. The bottom rail has double tenons with a bridge between the mortises. The muntins are mortised into the rails. The panels should be kept from $\frac{1}{8}$ to $\frac{3}{16}$ in. less than the width of the space between grooves, to permit expansion.

In putting the door together, only the shoulder, or that portion of the tenon next the panel, should be glued, so that in case of shrinkage or swelling the joints will remain close. When the stiles are driven up and the clamps applied, the wedges *l* should be well fitted, should have the edges next the tenons brushed with glue, and be driven in tightly. The horns *m*, or extra lengths of the stiles during construction, are designed to withstand the pressure exerted when the end wedges are driven in. These would otherwise be forced out by shearing the fibers of the wood beyond the mortise, thus destroying the joint.

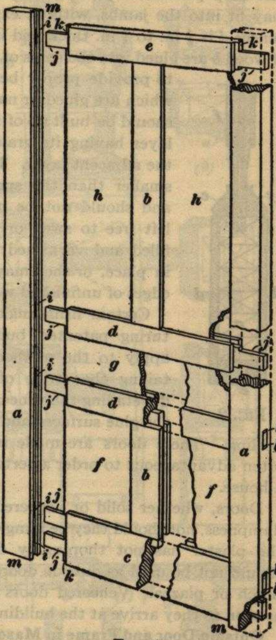


FIG. 1

**Built-Up Doors.**—Where a better grade of door is desired, it is built up as shown in Fig. 2, which is a section of the stiles and rails around the outer edges of the door. These stiles and rails are built up of several strips of clear white pine

$\frac{7}{8}$ in. thick, glued together, which form the *core*. The outer edges of the door are covered with a $\frac{7}{8}$-in. strip *e* of the same wood that is used for veneering the door. The thickness of this strip permits of planing the edges of the door so that it may fit into the jambs, without exposing the pine core. The veneer *d* is $\frac{1}{8}$ in. to $\frac{1}{4}$ in. thick and is glued to the core. Strips of wood *b* are glued into the cores of all rails, stiles, and muntins to provide proper bearings for the moldings *c*, which are glued or nailed to them. The panels *f* should be built up of five plies of veneering, each layer having its grain at right angles to that of the adjacent layer. The panels are made slightly smaller than the space enclosed by the strips and should not be nailed or glued in place but left free to swell or shrink. Panels should be filled and varnished, or painted before being set in place, or they may shrink later on and show edges of unfinished wood.

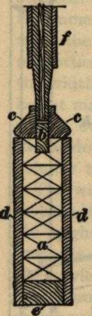


FIG. 2

Certain firms make a specialty of manufacturing patented built-up doors. The patents apply to the method of interlocking or dovetailing the strips of the core together and of dovetailing the veneer to the core, thus increasing the glue surfaces and preventing the veneer from peeling. These doors are made in great quantities and it is often advantageous to order a certain make of door in building a house.

Doors, whether solid or veneered, should not be exposed to dampness, nor should they be hung or stored in a building where the plaster has not thoroughly dried out. Veneered doors should not be used as outside doors unless well protected by a porch or piazza. Veneered doors should be filled or painted as soon as they arrive at the building.

**Outside Door and Frame in Masonry Wall.**—In Fig. 3 (*j*) is shown a detail drawing of a door and door frame in a masonry wall. The frame *a*, which is generally set when the building is nearly finished, is made somewhat smaller than the masonry opening. It is then *blocked* with rough lumber or studs *b*, which are securely fastened to the wall and support the frame.

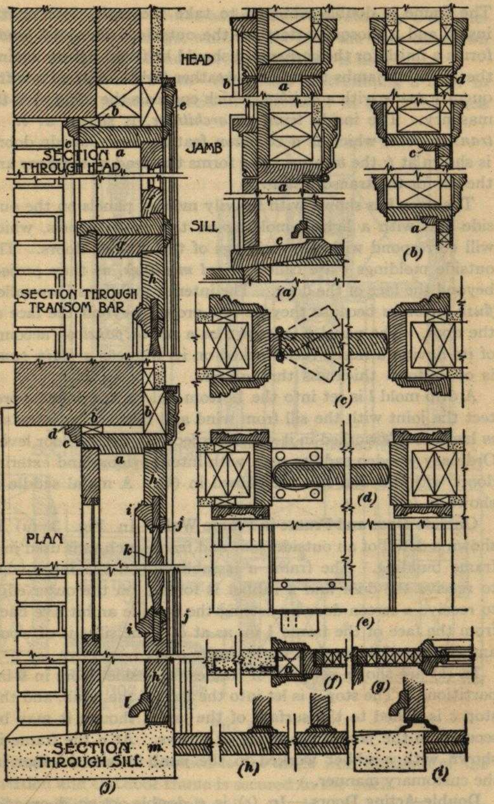

HEAD
JAMB
SILL
SECTION THROUGH HEAD
SECTION THROUGH TRANSOM BAR
PLAN
SECTION THROUGH SILL
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)

FIG. 3

The frame is double-rabbeted to take the main door on the inside and a mosquito door on the outside. The *staff bead c* forms a finish for the corner and should be fitted tightly against the masonry jambs to make a weather-tight joint. It is frequently made with a *quirk d*, which conceals the joint with the masonry. The inside trim, or *architrave*, is shown at *e*. A *transom sash*, which is a common feature over outside doors, is shown at *f*; the *transom bar g* forms the head of the door and the sill for the transom sash.

The door *h* is shown with heavily molded panels on the outside and with a lighter molding on the inside panels, which will correspond with the moldings of the interior doors. The outside moldings *i* are called *raised moldings*, as they project beyond the face of the door. The interior moldings *j* are called *flush moldings* because they do not project beyond the face of the door. The panel *k* is known as a *raised panel* on account of its having a raised face worked on it, whereas a *plain panel* is of uniform thickness throughout.

A drip mold *l* is set into the bottom rail of the door to protect the joint with the sill from wind and rain. The stone sill *m* has a *saddle* worked in it which projects above the floor level. Ordinary wooden saddles used with interior doors and exterior doors with wooden sills are shown in (*h*). A metal saddle is shown in (*i*).

**Outside Door and Frame in Frame Wall.**—In Fig. 3 (*a*) is shown a detail of an outside door and frame such as is used in a frame building. The frame *a* is rabbeted on the inner edge to receive the door and a rabbet is formed on the outer edge to receive a screen door by setting the outside architrave back from the face of the frame ½ in. as at *b*. The sill *c* is of wood and has a saddle worked on its inner edge.

In (*b*) are shown sections of frames for inside doors in 6-in. partitions. The stop *a* is let into the face of the jamb, and the stop *c* is nailed to the surface of the jamb, though it may be secured to the jamb by adjustable screws. At *d* the frame is shown with a rabbet worked in the jamb to take the door in the customary manner.

**Double-Acting Doors.**—In (*c*) is a double-acting door and frame. The door is hung on double-acting spring hinges.

In (*d*) is shown a double-acting door operated by a double-acting spring floor hinge, which is let into the floor as shown in (*e*). At the top of the door, a plain pivot is used.

**Doors in 2-In. Partition.**—A method of trimming a door in a 2-in., solid, plaster partition is detailed in (*f*). The buck

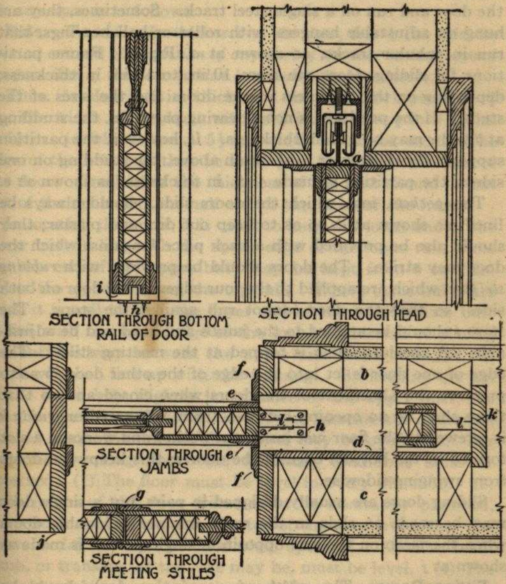



FIG. 4

or rough frame *a*, is fastened to the angle iron uprights of the partition and the door frame is secured to the buck.

**Doors With Glass Panels.**—In (*g*) is detailed a section through the side rail of a door with a glass panel surrounded by

a raised molding. The molding is divided on one side of the door and the glass is held in position by nailing the small portion of the molding in place.

**Sliding Doors.**—Sliding doors differ from ordinary doors chiefly in the method of hanging them. Generally they are hung with overhead hangers, which are secured to the top of the door and run on a single steel track. Sometimes, they are hung on adjustable hangers, with roller or ball bearings, that run in tubular tracks, as shown at *a*, Fig. 4. Frame partitions for sliding doors are from 10 in. to 13 in. in thickness, depending on the thickness of the doors and the sizes of the studs. If the partition is not a bearing partition, the studding at *b* and *c* may be 2 in. in thickness. If, however, the partition supports floorbeams or a partition above, the studding on one side of the partition is made 4 in. in thickness, as shown at *c*.

The *pockets*, into which the doors slide, should always be lined, as shown at *d*, so as to keep out dirt and plaster; they should also be provided with a back piece *k* against which the door may strike. The doors should be provided with *rubbing strips e*, which are applied to the four edges of the door on both sides, so that the door cannot rub against the stops. The *stops f* should be applied to the jambs and head and be adjustable. A special joint *g* is formed at the meeting stiles. The edge of one door is let into the edge of the other door so as to preserve the alinement of the doors when closed and so that there shall be no opening between them. A cast-iron *guide h* is screwed to the floor just inside the pocket and works in a slot formed in the bottom edge of the door *i*; this keeps the doors from swinging sidewise.

Sliding doors are usually designed in pairs, but a single door may be made to slide in the same manner as double doors when the jamb on the side opposite a single pocket is made as shown at *j*

**Fitting Doors.**—The width of a swinging door should be about $\frac{3}{16}$ in. less than the width between the jambs, allowing a clearance of about $\frac{3}{32}$ in. on each side, and the opening edge should be slightly beveled. The standard bevel to which locks are made is $\frac{1}{8}$ in. in $2\frac{1}{4}$ in., but where the door is narrow, it may require the lock-face beveled to as much as $\frac{1}{4}$ in. in 2 in.,

or even more. An equal clearance should be left at the upper rail, while the bottom rail may require from $\frac{1}{4}$ in. to $\frac{1}{2}$ in., in order that the door may swing clear of the floor covering. If saddles are used the door should clear the saddle by about $\frac{3}{32}$ in.

**Butts.**—A simple rule for finding the width of butt required for any door is as follows:

**Rule.**—*To twice the thickness of the door, less $\frac{1}{2}$ in., add the greatest amount of projection of any part of the door casing beyond the face line of the door (which is usually the base block).*

Thus, if a door is 2 in. thick, and the base block projects $1\frac{7}{8}$ in., the width of the butt will be 2 in.+2 in.$-\frac{1}{2}$ in.$+1\frac{7}{8}$ in. $=5\frac{3}{8}$ in., in which case a $5\frac{1}{2}$ in. width would be used. The edge of the butt will thus be kept $\frac{1}{4}$ in. back from the face of the door. One-half of the thickness of the butt should be cut out of the door, and one-half out of the jamb of the frame.

In locating the butts, it is usual to keep the lower end of the lower butt in line with the upper edge of the lower rail, while the top end of the upper butt may be kept from 6 to 7 in. below the upper edge of the top rail. Where three butts are used, it is well to keep the lower end of the intermediate butt in line with the upper edge of the lock-rail, instead of placing the butt midway between the upper and lower butts, as the butts will then line up with the framing. By keeping the pin of the lower butt slightly in advance of the upper butt, the door, in opening, will rise at the toe and increase the clearance, so that inequalities in the floor level may be overcome. For first-class working doors the following conditions must be observed: (1) The floor must be level in every direction. (2) Both jambs of the door frame must be accurately plumbed, facewise and edgewise, else the toe of the door will either rise above or fall toward the floor when operated. (3) The head-jamb, or transom, as the case may be, must be level. (4) The butts must be of good quality, well-fitted, and the pins kept true to line.

## TRIM

The finish of doors and windows is called the *trim*, *casings*, or *architraves*. The simplest form of casing consists of a board 5 or 6 in. in width mitered around the opening. The finish of

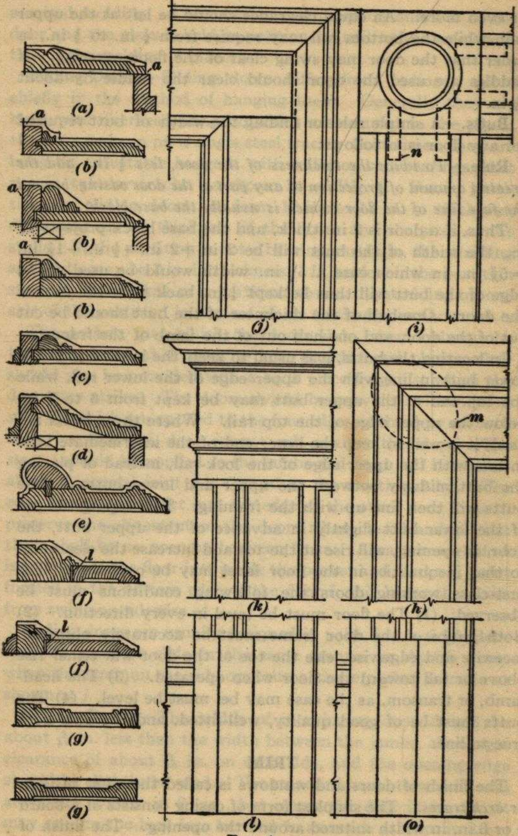



FIG. 1

doors and windows is capable of very elaborate treatment in which columns, pilasters, cornices, and pediments are used and in which elaborate carving may be employed. A few simple casings are shown in Fig. 1.

The casings shown in (*a*), (*b*), (*c*), (*d*), (*e*), and (*f*) are used for mitered effects such as are shown in (*h*) and (*j*). In (*a*) the casing is made of a single strip of wood and the back is plowed out in order to prevent warping and twisting. The trim of a door is generally set back from the face of the door frame about ¼ in., as at *a*, so that the butt, or hinge, when let into the face of the jamb will not cut through the trim.

In (*b*) are casings that are built up of three pieces, the piece *a* being called the *back band*. The flat member of the trim is let into the back band and a molding is planted in the corner. This construction permits the use of thin stock in making the trim, which is an economy, and the wood is not apt to curl or warp.

In (*c*) a similar trim is shown having a *back molding* set against the back band and scribed against the face of the plaster. The back molding is often carried around the trim of a door or window and across the top of the chair rail, base or wainscoting.

In (*d*) is shown a *sprung trim*, made of two pieces of thin material; this trim shows a heavy projection and at the same time is economical of stock.

In (*e*) is a trim with a large ovolo as its principal feature. The ovolo is made of a separate strip and glued and splined to the body of the trim.

A form of trim where the joint *l* is covered by a projection worked in the back band is shown in (*f*).

Casings, sometimes called *pilaster casings*, are shown in (*g*). They are generally used with corner blocks as shown in (*i*). The casings are butted against the blocks and are sometimes joined together by means of round dowels glued in, as shown at *n*.

Mitered casings made of one strip of wood are generally mitered together as shown in (*h*). A hardwood spline, or tongue, *m* should be inserted into grooves cut in the ends of the casings by a circular saw. The spline should be set with

the grain at right angles to the miter cut and glued in place. When the trim is built up of two or three pieces as in (*b*), (*c*), and (*f*), the joint is best made by butting the flat face of the casing and mitering the moldings as in (*j*). This method of joining casings prevents the opening up of the joint due to shrinkage which is so common with plain mitered joints.

Among other forms of casings, or trim, is that shown in (*k*), which consists of pilaster casings on the sides of the opening and a simple form of entablature over the head. This entablature is formed of a plain board with a small mold bradded or glued to the face and a small cornice molding mitered around the top.

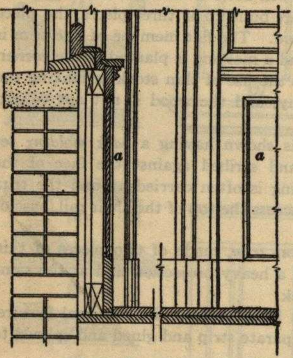



FIG. 2

In the details of windows previously given are shown examples of window finishes. Where the wall is thin, the casing is stopped on a stool with an apron and bed mold below. Where the wall is thick, as in masonry walls, jamb casings are required to fill the space between the box and the face of the plaster. When the casings are carried to the tops of plinth blocks, the trim is like that of a door.

Where the wall is very thick, the part under the window frame and between the jambs of the masonry opening is sometimes made thinner and the recessed surface under the window frame is paneled as shown in Fig. 2. The jamb casings and the trim of the window extend to the floor. The paneled surface *a* is called a *panel back*.

*Plinth blocks* are placed at the bottoms of casings as shown in Fig. 1 (*l*) and (*o*). This treatment is generally used with door casings and with the casings of windows that are carried

to the floor. The use of plinth blocks avoids the necessity of carrying the fine moldings of the casing to the floor, where they are apt to be filled with dirt, and provides a sufficient thickness of material to receive the base. Plinth blocks are usually shaped to match the profile of the casing and in Fig. 1 the sections of casings in views (*a*), (*b*), etc., have profiles of plinth blocks shown on them. In the case of a pilaster casing (*g*) the plinth block may be a plain rectangular board, and in the casing (*e*) it may be elaborately molded, but should have no fine moldings or quirks.

## BASES

*Bases, base boards,* or *skirtings* are boards fitted against the walls at their intersection with the floor. In closets and unimportant rooms, the base consists of a ⅞-in. board with a simple molding on top, as in Fig. 3 (*a*). A quarter-round molding *b* is frequently fitted into the angle of the base and floor so as to conceal the crack that will appear if the base shrinks. Where there is a double floor, the base is set before the finished floor is put in place and the floor is fitted against the base as shown in (*a*), (*b*), and (*c*).

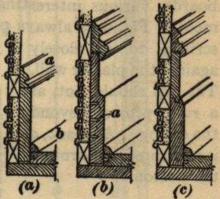


FIG. 3

In (*b*) is shown a more elaborate base formed of a molded board with a rich molding rabetted on top. A still more elaborate base, consisting of three pieces, is shown in (*c*). Suitable grounds are shown for nailing these various bases in place. The base is sometimes sawed lengthwise through about one-half of its thickness, as shown at *a* in (*b*), to prevent warping and twisting. Housekeepers object to bases with projecting moldings as they catch dust; it is therefore desirable that the moldings should have as slight projections as possible.

## CHAIR RAIL

A molded band, or *chair rail, a,* Fig. 4, is sometimes applied to plastered walls to prevent the backs of chairs from marring the plastering or papering. It should be about 4 in. or 5 in.

in width and should be placed about 3 ft. above the floor; the projection should be less than that of the door and window casings against which it runs. Suitable grounds *b* should be provided for nailing the chair rail to the wall.

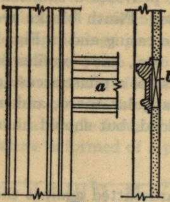



FIG 4

## WAINSCOTING

The wall is sometimes covered for its whole height, but more often to the height of 3 ft. or 4 ft. with a wainscoting. This wainscoting may be made of marble or wood and in its simplest form consists of matched boarding crowned with a simple cap mold Fig. 6. The matched boarding may have a V-joint as shown in Fig. 5 (*a*); a beaded joint as in (*b*) or a molded face like that shown in (*c*). This boarding, which is also called *ceiling*, is nailed to grounds by blind nailing in the same manner as flooring. By other treatments of the faces of the boards, various interesting effects may be obtained. A cap mold *a*, Fig. 6, is always placed on top of the boarding and is scribed to fit closely against the plaster wall. The cap should not, as a rule, project beyond the casing. A base *c*, *d* is sometimes run around the bottom.

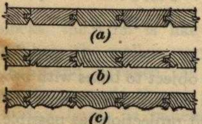



FIG. 5

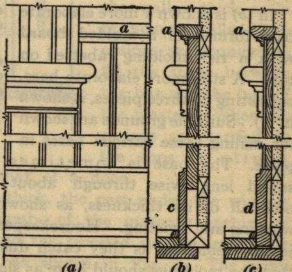



FIG. 6

*Paneled wainscoting* should be constructed with the same care as is used in making doors. In the best work the rails

and stiles are veneered and the panels made up of five thicknesses of veneer. The panels are glued up with the grain of one layer at right angles to the grain of the next layer. Paneled wainscoting should be put together at the shop and brought to the building in lengths ready to fit into position. Fig. 7 shows a detail of a paneled wainscoting with the cap *a* and a small molding *b* let in to form a frieze. At *c* is a rail,

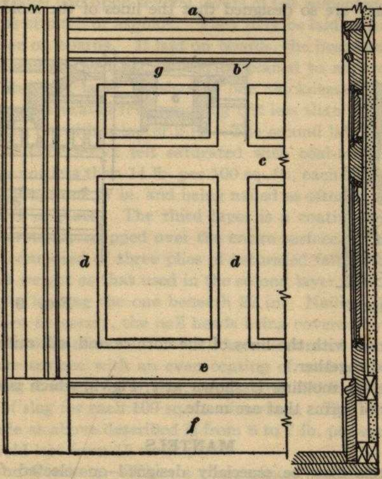



FIG. 7

at *d* the stiles, and at *e* the bottom rail with a base *f*. The panels should be put in, as shown in Fig. 8. The molding *a* is glued to the stile, or rail *b*, which is rabbeted to receive it. The panel, having been filled and varnished or painted, is set in from the back and secured in place by means of strips of wood nailed to the stile. The panels should not be glued or

nailed in place, but left free to swell or shrink. The plastering behind the wainscoting should be kept free from the wainscoting. This is accomplished by omitting the finishing coat and sometimes the brown coat of plastering.

## INSIDE CORNICES AND PICTURE MOLDINGS

Cornices of wood, such as are shown at *a* Fig. 9, are frequently used. Where false beams, such as shown at *b*, are used, they are so designed that the lines of the moldings will

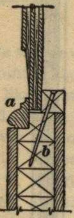



FIG. 8

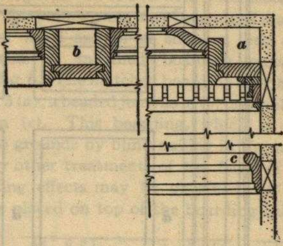



FIG. 9

correspond with the lines of the cornice and will miter or can be coped together.

A picture molding is shown at *c*, Fig. 9, which is one of a number of forms that are made.

## MANTELS

Mantels may be especially designed or selected from the catalogs of manufacturers. They are made of wood, marble, stone, and imitation stone. Wood mantels are made of the same wood and finish as the trim of the room, and may be of hardwood with natural finish or of soft wood painted or enameled. Marble and stone are used for expensive mantels in which carving is employed; field stone is used where a rustic effect is desired. Mantels modeled after fine examples are cast in artificial stone and are shown in the manufacturers' catalogs.

# ROOFING

## COMPOSITION ROOFS

**Laid on Boards.**—*Composition roofs*, are roofs made with slag or gravel laid upon several layers of felt cemented together by means of pitch or asphalt. They may be laid on a concrete surface or on boards. If laid on boards, the boards should be tongued-and-grooved and should be planed to an even thickness. The first layer consists of one thickness of sheathing paper or unsaturated felt, weighing not less than 5 lb. per 100 sq. ft., put on with a lap of 2 in. The second layer is formed of two thicknesses of felt saturated with coal-tar pitch and weighing not less than 14 lb. per 100 sq. ft., each sheet lapping over the lower one 17 in. and being nailed as often as necessary to keep it in place. The third layer is a coating of coal-tar pitch thoroughly mopped over the entire surface. The fourth layer is composed of three plies of saturated felt, of the same kind and weight as that used in the second layer, laid in pitch, each layer lapping the one beneath 22 in. Nailing should be done when necessary, the nail heads being covered by at least two thicknesses of felt. The fifth layer is formed by mopping the entire surface with an even coating of coal-tar pitch and imbedding it in gravel or slag, using about 400 lb. of gravel or 300 lb. of slag for each 100 sq. ft. of surface. The weight of a roof made as above described is from 6 to 7 lb. per square foot and should last from 15 to 20 yr.

**Laid on Concrete.**—When a composition roof is to be laid upon a concrete or cement surface, the first layer should be of coal-tar pitch mopped on uniformly. The second layer should consist of two thicknesses of saturated felt laid in pitch with a 17 in. lap. The remaining layers are the same as for the roof on boards.

The roof on concrete is often finished with flat tiles or brick in place of the slag or gravel and may be set either in a bed of Portland-cement mortar or in pitch.

Asphalt may be used in place of coal tar pitch for saturating the felt and for mopping the roof.

**Ready Roofings.**—Ready roofings, consisting of two or three layers of felt and burlap cemented together with coal-tar pitch or asphalt, and sometimes covered with grit or gravel, are sold in rolls. Accompanying the rolls are the necessary accessories, such as nails and cementing materials. These roofings are easily applied and form a serviceable roof for sheds and outhouses.

*Flashings* used in connection with composition roofing should be of copper, galvanized iron, or tin.

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## SHINGLES

**Description.**—The best shingles are made of cypress, redwood, and cedar. They are ordinarily 16 in. and 18 in. in length, but are sometimes made as long as 27 in. or 30 in. Common shingles are made in random widths varying from $2\frac{1}{2}$ in. to 14 in. The thickness at the *butt*, or thick end, varies from $\frac{7}{16}$ in. to $\frac{3}{16}$ in. and the thickness at the upper end is $\frac{7}{16}$ in. They are packed in bundles that contain the equivalent of 250 shingles 4 in. wide, and are sold at so much per 1,000 shingles or four bundles.

*Dimension shingles* are always cut to a uniform size or width, and are preferable in laying patterns; they are 4, 5, or 6 in. in width, and are usually dressed.

*Shaved shingles* are split and shaved with the drawknife but are difficult to obtain as shingles are generally sawed.

*Clear butts* indicate that the shingles contained in the bundle have a clear butt, or enough clear surface for the exposure to the weather.

*Fancy butts*, or *pattern butts*, are shingles having the butts, or ends, sawed to a geometric or other form, such as saw tooth, round, hexagonal, etc. These shingles are usually dressed.

*Shingle lath*, on which the shingles are laid, usually runs from $1\frac{1}{4}$ in. $\times$ 2 in. to $1\frac{1}{4}$ in. $\times$ 3 in.

*Valley, hip*, and *ridge boards* are of either 1 in. or $1\frac{1}{4}$ in. in thickness, as required.

**Methods of Laying.**—The methods of laying shingles generally in use are: on shingle lath, on boarding without paper or felt, and on matched boarding and lath with felt. The first method is undoubtedly the best, though it is generally used only on cheap buildings. In more expensive houses, the requirements usually call for a matched-board roof. This method, however, prevents the free circulation of air under the shingles and causes them to decay quite rapidly.

The starting course of shingles should be doubled at the eaves and the ends should overlap the gutter about $1\frac{1}{2}$ in. Each shingle is fastened with two fourpenny nails, and is exposed from $4\frac{1}{2}$ in. to 5 in. on the roof and from 5 in. to 6 in. on the sides of the building.

Along the valleys *c*, Fig. 1, tilting fillets *a* should be placed over which the flashing *b* is formed. Similar tilting fillets should be placed along the upper edge of the gutter just above the overflow.

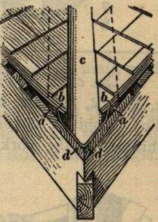


FIG. 1

**Finding the Gauge.**—The *gauge* or exposure to the weather of a shingle is obtained by subtracting the lap from the length and dividing the difference by 3. Thus, for a shingle 18 in. long, with a 3-in. lap, the exposed length will be 18 in. minus 3 in., or 15 in., which, divided by 3, will give 5 in.

The number of inches exposed to the weather multiplied by the average width of a shingle gives the area of the exposure; dividing 14,400 (the number of square inches in 100 sq. ft.) by the area of the exposure gives the number of shingles required to cover 100 sq. ft. of roof. For example, the average width of a shingle is 4 in., and if exposed to the weather 4 in., the area of exposure is 16 sq. in.; now, 14,400 sq. in. divided by 16 gives 900, which is the number of shingles required per square.

**Number of Shingles Required.**—The table on page 308 is arranged for shingles from 16 in. to 27 in. in length, and is based on a given exposure to the weather.

**Hips and Valleys.**—Valleys are of two kinds as regards finish. The *open valley* is shown in Fig. 1. The shingles or slates are

kept apart so that 8 in. or 10 in. of the metal, with which the valley is lined, is exposed. Before the shingling is begun, a long strip of metal *c* is laid on the boards *d* and over the tilting fillets *a*. The shingles are then laid as already described.

**SHINGLES REQUIRED FOR ROOFING**

| Exposure to Weather Inches | Square Feet of Roof Covered by 1,000 Shingles | | Shingles Required for 100 Sq. Ft. of Roof | |
|---|---|---|---|---|
| | 4 In. Wide | 6 In. Wide | 4 In. Wide | 6 In. Wide |
| 4 | 111 | 167 | 900 | 600 |
| 5 | 139 | 208 | 720 | 480 |
| 6 | 167 | 250 | 600 | 400 |
| 7 | 194 | 291 | 514 | 343 |
| 8 | 222 | 333 | 450 | 300 |

In the *close valley* the shingles or slates almost meet as at *b*, Fig. 2, so that the metal flashings *a* and *c* do not show. The flashings consist of sheets of metal laid between the shingles as the work progresses.

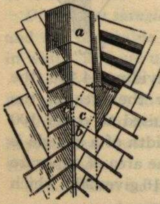



FIG. 2

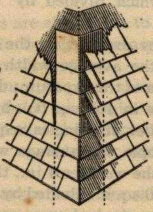


FIG. 3

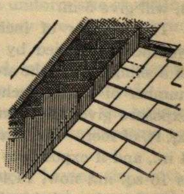


FIG. 4

The flashing of hips, as in Fig. 3, and the intersections of roofs with gable walls, as shown in Fig. 4 is done in the same manner as that of close valleys. The *Boston hip*, shown in Fig. 5, gives a very neat finish to the hip. Shingles of a

uniform width of, say, 5 in., should be selected. A chalk line is snapped on each side of the hip, about $4\frac{1}{2}$ in. from its center and parallel to it, as shown at *a*, Fig. 5. The slope shingles on the main roof should be carried up to this line, stepping back to allow the hips to be laid last. Lay the bottom shingles first with their edges at, and parallel to, the hip line, and the lower corners of their butts just touching the butts of the shingles below, as shown. Across each hip shingle, and at right angles to the eaves, draw a line for the vertical side cut, as at *c*. Slightly taper the side *d* to secure a close fit at the intersection. Fit the hip shingle to the side of the main roof shingle, and nail in place as shown.

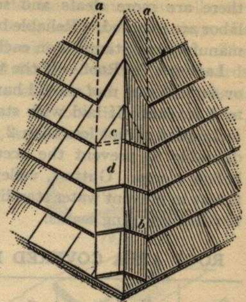


FIG. 5

One of the chief advantages of this method is that the grain of the wood runs with the hip, and the tendency to curl is taken away from the line of the hip to the side of the shingle.

## SHEET-METAL ROOFS

### TIN ROOFS

*Roofing tin*, or *terne plates*, are made of sheets of soft steel or iron coated with tin or tin and lead. The sizes of sheets generally used are 14 in. × 20 in. and 20 in. × 28 in. The thickness of the plates is described by the signs IC, IX, etc. IC represents a plate of 30 gauge and weighing about 10 oz. per sq. ft.; IX corresponds to 28 gauge and weighs about 12 oz. per sq. ft. The gauge is the United States standard. A box of tin plates contains 112 sheets. Measurements of tin roofing are based on a square of 100 sq. ft. The accompanying table shows the number of square feet of roof a box of tin plates will cover.

The cost of laying 14″×20″ plates will amount to about 25% more than the cost of laying 20″×28″ plates, because there are more cleats and seams, so that more solder and labor are required. Reliable brands of tin have the name of the manufacturer stamped on each sheet of tin.

**Laying a Tin Roof.**—If the tin is to be laid with a *flat seam*, or *flat lock*, the roof should have an inclination of ½ in. or more to 1 ft. run. If laid with standing seams, it should have an inclination of not less than 2 in. to the foot. A good pitch is desirable to prevent the accumulation of water and dirt in hollow places. Gutters, valleys, etc., should have a pitch sufficient to prevent water standing in them or backing up enough to reach standing seams.

**ROOF AREA COVERED BY A BOX OF TIN PLATES**

| Size of Plates Inches | Thickness | Gauge Number | Sheets in Box | Weight per Box Pounds | Square Feet of Flat Seam | Square Feet of Standing Seam | Weight per Square on Roof Pounds |
|---|---|---|---|---|---|---|---|
| 14×20 | *IC* | 30 | 112 | 107 | 180 | 165 | 65 |
| 14×20 | *IX* | 28 | 112 | 135 | 180 | 165 | 82 |
| 20×28 | *IC* | 30 | 112 | 214 | 381 | 360 | |
| 20×28 | *IX* | 28 | 112 | 270 | 381 | 360 | |

Tin roofs should be laid on tongued-and-grooved sheathing boards, which should be of well-seasoned, dry lumber of narrow widths, free from holes, and of even thickness. A new tin roof should never be laid over old tin, shingle, or tar roofs. Sheathing paper is not necessary where the boarding is laid as just specified. If, however, steam, fumes, or gases are likely to reach the under side of the tin, a good waterproof sheathing paper should be used under the tin. Tar paper should never be used.

**Flat-Seam Tin Roofing.**—Flat seams should be made as shown in Fig. 1 (*a*) to (*f*). When the sheets are laid singly, they should be fastened to the sheathing boards by cleats, Fig. 1 (*b*) and (*c*), using three cleats to each sheet, two on the

long side and one on the short side. Two 1-in., barbed, wire nails should be used to each cleat, but nails should never be driven through the sheets. If the tin is put on in rolls, the sheets should be made up into long lengths in the shop, the cross-seams locked together and well soaked in solder. The rolls should be edged ½ in. and fastened to the roof boards with cleats spaced 8 in. apart, and locked into the seam. The cleats should be fastened to the boards with two 1-in., barbed, wire nails to each cleat, as shown in Fig. 1 (*c*).

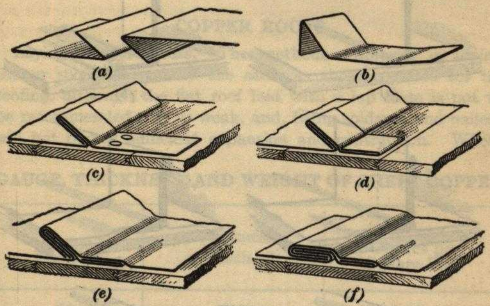


FIG. 1

**Standing-Seam Tin Roofing.**—The method of making standing seams is shown in Fig. 2 (*a*) to (*f*). For this kind of roofing, the sheets of tin should be put together in long lengths in the shop, the cross seams locked together and well soaked with solder. The sheets should be applied to the roof the narrow way and fastened with cleats spaced 1 ft. apart. One edge of the strip is turned up 1¼ in. at right angles to the sheet and the cleats installed as shown in (*b*). The adjoining edge of the next course is turned up 1½ in. as in (*c*) and these edges locked together, as shown in (*d*), turned over, as in (*e*), and the seam left, as shown in (*f*).

Valleys and gutters in all cases should be covered with IX tin and formed with flat seams, applying the sheets the narrow

way. It is important that good solder be used, bearing the manufacturer's name and guaranteed to consist of one-half new tin and one-half new lead. Rosin should be used as a flux. The solder should be well sweated into all seams and joints.

**Painting Tin Roofs.**—All painting should be done by the roofer. The tin should be painted one coat on the under side before it is applied to the roof. The upper surface of the tin

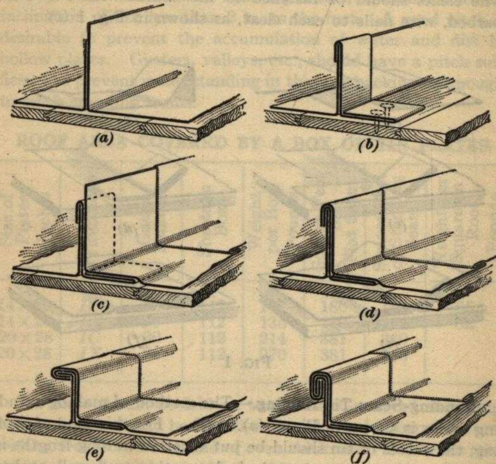



FIG. 2

roof should be carefully cleaned of all rosin, dirt, etc. and immediately painted. The most approved paints for this purpose are metallic brown, Venetian red, red oxide, and red lead, mixed with pure linseed oil. No patent dryer or turpentine should be used. All the coats of paint should be applied with a hand brush and well rubbed on. A second coat of paint should be applied 2 wk. after the first. The third coat should be put on about 1 yr. later.

**Caution.**—All unnecessary walking on a tin roof should be avoided as well as storing building or other materials on it. The tin surface is easily scratched from the iron plates, which exposes these plates to corrosion. Workmen should wear rubber-soled shoes or overshoes when working on the roof.

**Maintenance of Tin Roofs.**—To keep a tin roof in good condition, it should be painted at intervals of from 3 to 5 yr., depending on the slope of the roof and on local conditions. The gutters should be kept free from deposits of dirt and leaves and painted more frequently.

## COPPER ROOFS

**Laying Copper Roofs.**—The methods employed in laying copper roofs are usually the same as those required for tin roofing, although the flat roof laid with a lap seam is not to be recommended. It is weak, and, being soldered and nailed, will not permit sufficient expansion and contraction. Where

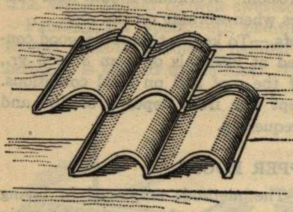
**GAUGE, THICKNESS, AND WEIGHT OF SHEET COPPER**

| Gauge Number | Thickness Inch | Weight Ounces per Square Foot |
|---|---|---|
| 29 | .0134 | 10 |
| 27 | .0161 | 12 |
| 26 | .0188 | 14 |
| 24 | .0215 | 16 |
| 23 | .0242 | 18 |
| 22 | .0269 | 20 |

solder is used, the lock-seam with cleats is best. The copper should be thoroughly tinned before commencing to solder it.

The standing-seam method of laying should be employed where extra strength and stiffness are required, on very steep-pitched roofs, and on flat surfaces where work without solder is to be carried out. The gauge, thickness, and weight per superficial foot of copper used for roofing purposes, are given in the accompanying table.

**Copper Tiling.**—Copper roofing tiles are made in imitation of most of the different forms of terra-cotta tiles. A common form of copper tile used is the imitation of the Spanish clay tile, as here shown.

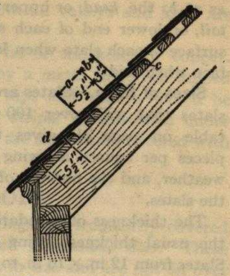


For straight surfaces the following sizes of tiles are used: 7 in. × 10 in., 10 in. × 14 in., and 14 in. × 20 in. The last size is best adapted for large roofs, but for ordinary roofs 10 in. × 14 in. is the size recommended. These tiles may be made of 12-oz., 14-oz., or 16-oz. copper. A square will require four hundred 7″ × 10″ tiles; one hundred and seventy-four 10″ × 14″ tiles; or seventy-two 14″ × 20″ tiles. These quantities allow for laps, waste, cutting, etc. All flashing on copper roofs is done with copper.

## SLATE ROOFS

**Qualities of Slate.**—Good slate should possess toughness, hardness, and a very fine, but easily distinguished, grain. The slates should be tough enough to be easily punched for nailing, and should cut to standard sizes without splintering or becoming friable at the edges. They should be hard enough not to absorb much moisture, as the action of frost on the moisture will cause the edges to crumble and will also tend to enlarge the nail holes, and thus cause the slate to loosen from the roof. The grain should run lengthwise of the slate. Veins or ribbons are objectionable markings, especially when parallel with the grain.

A good slate should present a bright, silk-like luster, and should emit a clear, metallic ring when struck with the knuckles, showing that it is hard; if it is soft, it will have a dull, lead-like surface, and will give out a muffled sound. When cut, the edges should show a fibrous-like texture, free from splinters,




and the material should not show signs of being either brittle or crumbly. No better test of the wearing or weathering qualities can be applied than the simple and effective one of examining roofs where similar slate has been in service for several years.

**Terms Used in Slating.** — The terms applied to the different parts of roofing slate are: the *gauge*, or *weather*, which is that part of the slate which is exposed when laid, as shown at *a*, in the accompanying figure; the *lap*, which is the distance that each slate overlaps the second one below it,

**QUANTITY OF SLATE AND NAILS PER SQUARE OF ROOF**

| Sizes of Slates Inches | Number in Square | Exposed to Weather Inches | Distances on Centers of Lath Inches | Pounds of Nails Required | | |
|---|---|---|---|---|---|---|
| | | | | Kind | Pounds | Ounces |
| 14×24 | 98 | 10½ | 10½ | 4-penny | 1 | 6 |
| 12×24 | 115 | 10½ | 10½ | | 1 | 10 |
| 12×22 | 126 | 9½ | 9½ | | 1 | 12 |
| 11×22 | 138 | 9½ | 9½ | | 1 | 15 |
| 12×20 | 142 | 8½ | 8½ | | 2 | 0 |
| 10×20 | 170 | 8½ | 8½ | | 2 | 6 |
| 12×18 | 160 | 7½ | 7½ | 3-penny | 1 | 13 |
| 10×18 | 192 | 7½ | 7½ | | 2 | 3 |
| 9×18 | 214 | 7½ | 7½ | | 2 | 7 |
| 12×16 | 185 | 6½ | 6½ | | 2 | 2 |
| 10×16 | 222 | 6½ | 6½ | | 2 | 8 |
| 9×16 | 247 | 6½ | 6½ | | 3 | 0 |
| 8×16 | 277 | 6½ | 6½ | | 3 | 2 |
| 10×14 | 261 | 5½ | 5½ | | 3 | 0 |
| 8×14 | 327 | 5½ | 5½ | | 3 | 12 |
| 7×14 | 374 | 5½ | 5½ | | 4 | 4 |
| 8×12 | 400 | 4½ | 4½ | | 4 | 9 |
| 7×12 | 457 | 4½ | 4½ | | 5 | 3 |
| 6×12 | 533 | 4½ | 4½ | | 6 | 1 |

as at *b;* the *head*, or upper end of each slate, as at *c;* and the *tail*, or lower end of each slate, as at *d.* The *bed* is the under surface of each slate when laid, and the *back* is the upper surface when laid.

**Sizes of Slate.**—Slates are sold by the square, or number of slates that will cover 100 sq. ft. of the roof surface. The table on page 315 gives the sizes of slates, the number of pieces per square allowing a 3-in. lap, the exposure to the weather, and the number of pounds of nails required in laying the slates.

The thickness of standard slates varies from $\frac{1}{8}$ in. to $\frac{3}{8}$ in., the usual thickness being $\frac{3}{16}$ in. for slates of average size. Slates from 12 in.×16 in. to 12 in.×20 in. are most economical, as there are fewer pieces to lay than in the smaller sizes, and less loss from breakage than there would be in using the larger sizes. Slates should always be bored and countersunk at the quarry, instead of punched for nailing on the job. The accompanying table gives the weight of slate per square foot. The approximate weight of slate per square foot when laid upon the roof is $6\frac{1}{2}$ lb. for slate $\frac{3}{16}$ in. thick and $8\frac{3}{4}$ lb. for slate $\frac{1}{4}$ in. thick. The colors of slate are dark blue, blue-black, purple, red, and green.

**WEIGHT OF SLATE PER SQUARE FOOT**

| Thickness Inch | Weight Pounds |
|---|---|
| $\frac{1}{8}$ | 1.82 |
| $\frac{3}{16}$ | 2.73 |
| $\frac{1}{4}$ | 3.64 |
| $\frac{3}{8}$ | 5.46 |
| $\frac{1}{2}$ | 7.28 |
| $\frac{5}{8}$ | 9.06 |
| $\frac{3}{4}$ | 10.87 |
| 1 | 14.50 |

**Laying Slate.**—Slates are laid on boards, covered with tarred or waterproofed paper, on wooden battens or laths, or on channel or angle iron purlins, as in fireproof buildings. The strips and angle irons are set a distance on centers equal to the exposed surface of the slate. The slates are nailed to the boards and battens with 3-penny or 4-penny slating nails, the best of which are made of copper and have broad heads. Slates are secured to iron framing by tying with copper wire or by means of special fasteners. In first-class work, the top course of slate on the ridge and the slates for 2 ft. to 4 ft. from

all gutters and 1 ft. each way from all valleys and hips, are bedded in *elastic cement*.

Flashings for slate work may be of tin, zinc, or copper. The ridge is generally protected by a metal ridge roll lapped over the top of the slates. The hips and valleys should be protected by weaving in metal strips, as described under shingle roofs. The hips, however, are sometimes covered with metal hip rolls.

## TILE ROOFS

The flat roofs of fireproof buildings are frequently covered with flat vitrified clay tiles, called *Promenade tiles*. These tiles are 6 in.$\times$9 in.$\times\frac{3}{4}$ in. or 1 in. in size and are put on over four or five plys of tarred felt laid in pitch on the concrete surface of the roof construction. They are bedded in a heavy coating of asphalt. The joints between the tiles should be not less than $\frac{3}{8}$ in. wide and be half filled with asphalt; the upper half is then filled in with a strong cement grout.

For pitch roofs, tiles of various shapes are used, such as flat, Spanish or S-shaped tiles, and other special patterns. Suitable ridge rolls, hip rolls, crestings, and finials are made to be used with the various patterns of tiles, and are set in elastic cement or good Portland cement mortar. Tiles should be burned until vitrified. The standard color is red, but other colors can be produced by glazing. Tiles made of clear glass are sometimes inserted in the roof at places where skylights would otherwise have to be used.

Tiles used on pitch roofs weigh from 750 to 1,200 lb. per square and should be laid on a tightly boarded roof upon which a layer of good roofing felt weighing 30 lb. per 100 sq. ft. has been laid. Each tile is nailed to the roof with two barbed wire nails, preferably of copper.

Flashings used in connection with tile roofing should be of 16-oz. copper.

Cement roofing tiles are made of a mixture of Portland cement, sand, and coloring matter reinforced with wire mesh. They are generally 22 in.$\times$52 in. in size and $\frac{7}{8}$ in. thick, and weigh about 14 lb. per sq. ft. Special tiles have sheets of wire glass set in them, which afford light without the use of skylights.

## ASBESTOS SHINGLES

Shingles made of cement and asbestos are used as roofing material. They are tough, strong, non-absorbent, fireproof, and light in weight. They can be obtained in a variety of sizes, 16 in.×16 in., 12 in.×12 in., 8 in.×8 in., 16 in.×8 in., 12 in.×6 in., and 4 in.×8 in. all of which are about $\frac{1}{8}$ in. thick. The butts are formed in various shapes, similar to those of shingles or slates. They may be laid in the *French method*, which shows diamond shaped shingles with the diagonals running horizontally and vertically; also in the *American method*, which is the same method used for slate. The weight of the shingles per square, laid in the French method, with 12″×12″ shingles is 272 lb. and 160 shingles are required. The weight of shingles per square laid in the American method, with 12″×12″ shingles is 432 lb. and 240 shingles are required.

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## CANVAS ROOFS

For the floors of sleeping balconies and for roofs that are to be walked upon, canvas roofs are used. The canvas, or duck, should be closely woven and treated with chemicals to preserve it from mildew and decay. The canvas should weigh about 16 oz. per sq. yd. and its width should be from 21 in. to 42 in. It should be tightly stretched with a lap of 1 in. and tacked to the roof boarding with heavy galvanized iron or copper tacks $\frac{3}{4}$ in to $\frac{7}{8}$ in long and spaced about $\frac{1}{2}$ in. apart, after which it should be wet and while still damp given a good coat of oil paint. It is then finished with two or three coats of paint.

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## SNOW GUARDS

Snow guards are made in various forms and are used on all kinds of pitch roofs to prevent the snow from sliding down into the gutters and clogging them, thus causing the water to overflow outside of the building. They also prevent masses of snow from sliding off a roof and injuring persons.

# STEEL SQUARE

## DESCRIPTION

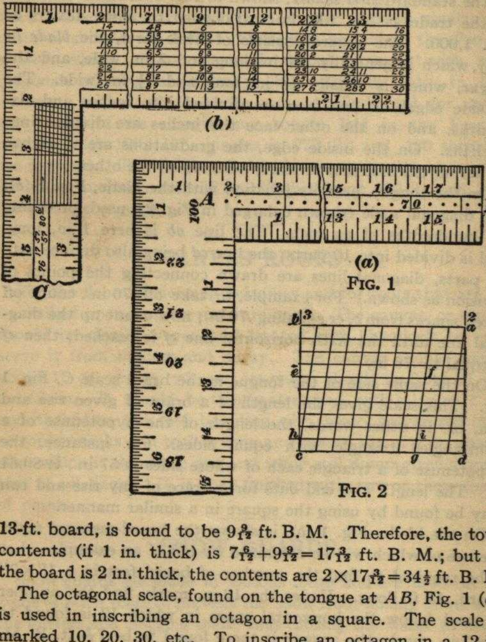
The standard *steel square*, shown in Fig. 1, is the one known to the trade as No. 100, but catalogued by some dealers as No. 1,000. The square consists of two parts, the *blade* or *body*, which is generally 24 in. long and 2 in. wide, and the *tongue*, which is usually 18 in. long and $1\frac{1}{2}$ in. wide. The outside edges on one face are divided into inches and sixteenths, and on the other face the inches are divided into twelfths. On the inside edge, the graduations are to eighth inches on one side and to thirty-seconds on the other.

On the tongue, near its junction with the blade, Fig. 1 (*b*), is a diagonal scale (shown enlarged in Fig. 2), used for taking off hundredths of an inch. The line *ab* is here 1 in. long, and is divided into 10 parts; the line *cd* being also divided into 10 parts, diagonal lines are drawn connecting the points of division as shown. For example, to take off .76 in., count off seven spaces from *c*, *cg* equaling .70 in.; now count up the diagonal line until the sixth horizontal line *ef* is reached; then *ef* is equal to .76 in.

On the same side of the tongue is the brace scale *C*, Fig. 1 (*b*). This scale gives the length of a brace of given rise and run, or, in other words, the length of the hypotenuse of a right-angled triangle with equal sides. For instance, the hypotenuse of a triangle each of whose sides is 57 in., is 80.61 in. The length and end cuts for a brace of any rise and run may be found by using the square in a similar manner.

On the blade, Fig. 1 (*b*), is shown the board-measure scale, the use of which will be explained by aid of an example. Let it be required to find the number of board feet in a $1'' \times 7''$ board, 13 ft. long. Under the 12-in. mark, find the number 13, and follow the horizontal space in which 13 is found to the 7-in. mark; the answer is there found to be $7\frac{7}{12}$ ft. B. M. If the board is over 1 in. thick, the problem is solved in the

same way, the result being multiplied by the thickness in inches. If the length of the board is greater than any number given under the figure 12, it should be divided into parts, as in the following example: Required the contents in board measure of a 2″×9″ plank, 23 ft. long. Divide the length into two parts, 10 ft. and 13 ft.; the contents of the 10-ft. part is found, as before shown, to be $7\frac{6}{12}$ ft. B. M.; that of the



(b)

(a)

FIG. 1

FIG. 2

13-ft. board, is found to be $9\frac{9}{12}$ ft. B. M. Therefore, the total contents (if 1 in. thick) is $7\frac{6}{12}+9\frac{9}{12}=17\frac{3}{12}$ ft. B. M.; but as the board is 2 in. thick, the contents are $2\times17\frac{3}{12}=34\frac{1}{2}$ ft. B. M.

The octagonal scale, found on the tongue at *AB*, Fig. 1 (*a*), is used in inscribing an octagon in a square. The scale is marked 10, 20, 30, etc. To inscribe an octagon in a 12-in. square (see Fig. 3), draw the lines *ab* and *cd*, bisecting the

sides; from *d* mark *de* and *df*, each equal to twelve divisions on the octagonal scale; mark *bg*, etc., in the same way, and draw *eg*, a side of the required octagon. The other sides may be similarly found. For a 10-in. square, make *de* equal to ten divisions; for a 7-in. square, equal to 7 divisions, etc.

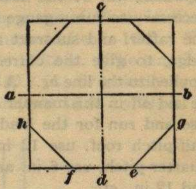



FIG. 3

In Fig. 4 (*a*) is shown an adjustable *fence*, a strip of hardwood about 2 in. wide, 1½ in. thick, and 2½ ft. long. A saw kerf, into which the square will slide, is cut from both ends, leaving about 8 in. of solid wood near the middle. The tool is clamped to the square by means of screws at convenient points, as shown. Let it be required to lay out a rafter of 8 ft. rise and 12 ft. run. Set the fence at the 8-in. mark on the blade, and at the 12-in mark on the tongue, clamping it to the square with 1¼-in. screws. Applying the square and fence at the upper end of the rafter, gives the plumb-cut *de* at once. By applying the square, as shown, twelve times successively,

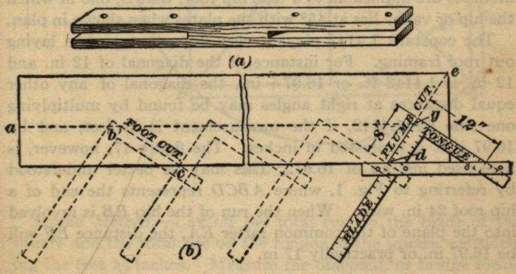



FIG. 4

the required length of the rafter and the foot-cut *cb* are obtained. In this case the twelve applications of the square are made

between the points *c* and *d*. Run and rise must also be measured between these points. If run is measured from the point *b*, which will be the outer edge of the wall plate, it will be necessary to run a gauge line through *b* parallel to the edge of the rafter, and subtract a distance *eg* from the height of the ridge, to give the correct rise. The square must then be applied to the line *bg*. A rafter of any desired rise and run may be laid off in this manner by selecting proportional parts of the rise and run for the blade and tongue of the square. For a half-pitch roof, use 12 in. on both tongue and blade; for a quarter-pitch, use 6 in. and 12 in.; for a third-pitch, use 8 in. and 12 in., etc.

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# USE OF STEEL SQUARE IN ROOF FRAMING

## INTRODUCTION

In treating of the uses of the steel square, special consideration should be given to its usefulness in roof framing, to which class of work it seems particularly adapted. The several members of the roof will be considered separately, showing in each case the more common methods of obtaining the lengths as well as the cuts by the use of the steel square. These methods are applicable to a true hip roof, that is, one in which the hip or valley lies at 45° with the plates when shown in plan.

The constant 1.4142 plays a very important part in laying out roof framing. For instance, if the diagonal of 12 in. and 12 in. is 1.4142 ft. or 16.97+ in., the diagonal of any other equal distances at right angles may be found by multiplying one side by 1.4142, if the measurement is in feet, and by 16.97 if it is expressed in inches. The figure 17, however, is here used instead of 16.97. This may be better understood by referring to Fig. 1, where *ABCD* represents the end of a hip roof 24 in. wide. When the run of the hip *EB* is revolved into the plane of the common rafter *EA*, the distance *EF* will be 16.97 in. or practically 17 in.

## COMMON RAFTERS

**Finding Length of Common Rafters.**—The length of common rafters for shed, gable, hip and valley roofs may be found by the following methods:

*First Method.*—Multiply the diagonal, or bridge, measure of 12 in. and the rise per foot of run of the common rafter, in inches, by the run of the common rafter, in feet. For example, in a $\frac{5}{12}$-pitch roof, that is one having a rise of 10 in. in 12 in. and a 20-ft. span, the run of the common rafter is 10 ft. The bridge measure of 10 in. and 12 in. is 15.62 in. The length of the rafter is therefore $15.62 \times 10 = 156.2$ in., or practically 13 ft. If a 2-in. ridge board is used multiply 15.62 by $9\frac{11}{12}$.

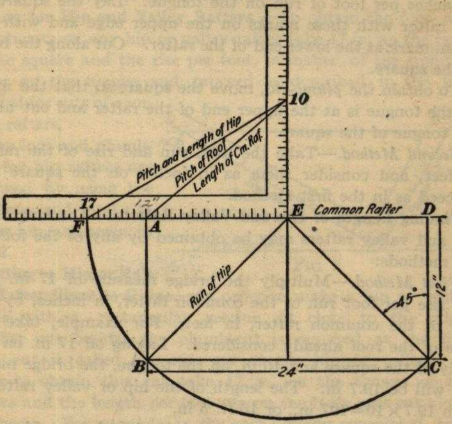



FIG. 1

*Second Method.*—Lay off the total run on the blade of the square and the total rise on the tongue of the square, considering the feet as inches. Measure the diagonal, or bridge measure, in inches and read it as in feet. Thus, illustrating with the same $\frac{5}{12}$-pitch roof, the total run is 10 ft., and the total rise is 100 in. or $8\frac{4}{12}$ ft. The bridge measure of 10 in. and $8\frac{4}{12}$ in. is 13 in. Therefore, the length is 13 ft.

If the ridge board is 2 in. thick, a portion of the rafter equal to one-half the thickness must be cut off. In practice, instead of making the two-cuts at the top of the rafter, allowance is made for the ridge board and the rafter is cut to the proper length by one cut.

**Cuts for Common Rafters.**—The cuts for common rafters are found by the following methods:

*First Method.*—To obtain the *foot-cut*, or cut at the foot of the rafter, take 12 in. on the body of the square and the rise in inches per foot of run on the tongue. Lay the square on the rafter with these marks on the upper edge and with the 12-in. mark at the lower end of the rafter. Cut along the body of the square.

To obtain the ***plumb-cut***, move the square so that the mark on the tongue is at the upper end of the rafter and cut along the tongue of the square.

*Second Method.*—Take the total run and rise of the rafter, in feet, and consider them as in inches on the square and proceed as in the first method.

**Finding Length of Hip and Valley Rafters.**—The lengths of hip and valley rafters may be obtained by any of the following methods:

Diagonal

*First Method.*—Multiply the bridge measure of 17 in. and the rise per foot run of the common rafter, in inches, by the run of the common rafter, in feet. For example, take the case of the roof already considered. Laying off 17 in. on the body of the square and 10 in. on the tongue, the bridge measure will be 19.7 in. The length of the hip or valley rafter is then $19.7 \times 10 = 197$ in., or 16 ft. 5 in.

*Second Method.*—The length may be found by taking the diagonal of the run of the hip or valley and the total rise. The run of the hip is obtained by taking the run of the common rafter on both the tongue and the body of the square, and measuring the diagonal. For example, calling the feet inches, lay off 10 in. on the tongue and 10 in. on the body of the square. Measuring the diagonal and calling the inches feet, the result is $14\frac{2}{12}$ ft. nearly, which is the run of the hip or valley. Again considering the feet as inches, lay off on the body of the square $14\frac{2}{12}$ in. for the run and on the tongue

$8\frac{4}{12}$ in. for the rise. Measure off the diagonal, read the inches as feet and the result will be 16 ft. 5 in., the length of the rafter.

A more accurate method of finding the run of a hip or valley rafter is to multiply the run of the common rafter by 1.4142 which gives $10 \times 1.4142 = 14.142$ ft. or 14 ft. 1.7 in.

*Third Method.*—Another method of finding the length of these rafters is to use 17 on the tongue of the square and the rise per foot run of the common rafter on the body and apply the square to the hip or valley rafter as many times as there are feet in the run of the common rafter.

**Cuts for Hip and Valley Rafters.**—To obtain the foot- and plumb-cuts on any hip or valley rafter take 17 in. on the body of the square and the rise per foot, in inches, of the common rafter on the tongue and proceed as described in the first method for cuts of common rafters.

The foot and plumb-cuts for hip rafters are obtained by using the total run and total rise of the hip, as shown in Fig. 2.

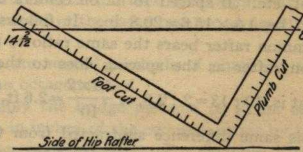


FIG. 2

**Fitting a Hip or Valley Rafter Close to Ridge.**—In order to make a hip or valley rafter with a rectangular section fit close to the ridge, another cut besides the plumb-cut is required at the top. This cut is called the *side cut* of the hip or valley. In order to obtain this cut take 17 in. on the tongue of the square and the length per foot run on the body and cut along the body. For example, in the roof already considered, take 17 in. on the tongue and $19\frac{8}{12}$ in. on the body, cutting along the body. A second method is to take the total run of the hip on the tongue and the total length of the hip on the body, considering the feet as inches and cut along the body.

When a hip or valley rafter is *backed*, or has the upper corners dressed off so that the top edge will be in the same planes as the roof on both sides of the rafter, the cuts for the backing are found by taking the rise per foot run of the common rafter on the tongue and the length per foot run of the hip or valley

on the body and cutting along the tongue. For example, take 10 in. on the tongue and $19\frac{8}{12}$ in. on the body and cut along the tongue.

## JACK-RAFTERS

**Finding the Length of Jack-Rafters.**—To find the difference in the lengths of jack-rafters, multiply the length, in feet, of the common rafter per foot of run, by the distance, in feet, between centers; subtract this product from the length of the common rafter, and it will give the length of the first jack-rafter, or the one next to the common rafter. For example, with a $\frac{5}{12}$-pitch, the length of the common rafter is 15.6 in. and the jack-rafters are spaced 2 ft. on centers. The first jack-rafter will be $2 \times 15.6 = 31.2$ in. shorter than the common rafter, the second jack-rafter will be 31.2 in. shorter than the first, etc. If spaced 16 in. on centers the difference in length will be $1\frac{4}{12} \times 15.6 = 20.8$ in. It follows that the run of the common rafter bears the same ratio to the length of the common rafter as the spacing does to the difference in length; that is, $10 : 13 = 2 : 2.6$, or $\frac{13 \times 2}{10} = 2.6$ ft. $= 2$ ft. $7\frac{2}{10}$ in. $= 31.2$ in. This same difference subtracted from the length of the first jack-rafter will give the length of the second jack-rafter.

**Cuts for Jack-Rafters.**—The foot- and plumb-cuts for jack-rafters are the same as the cuts for common rafters. Jack-rafters differ from common rafters, however, in that side, or *cheek cuts*, are required at the tops in order to make them fit against the hip or valley rafters. In order to obtain this cut, take 12 in. of the run of the common rafter on the tongue and the length of the common rafter per foot of run on the body, and mark along the body on the upper edge of the jack-rafter. Saw through this mark and at the same time follow the plumb-cut on the side of the jack-rafter. Thus, take 12 in. on the tongue and 15.62 in. on the body of the square and mark along the body. Then cut as described.

Diagonal of Rise + Run on Blade + Run on Tongue
Mark along Blade

## ROOF BOARDS

As the roof boards are at right angles to the jack-rafters, the face cut will be the same as the cheek cut of the jack-rafters, except that the cut is made along the tongue of the

square. For the *miter cut*, or cut on the edge, take the length of the common rafter per foot of run on the tongue, and the rise per foot of run on the body and cut along the body.

## PURLINS

The miter and face cuts for purlins are the same as for roof boards.

## SHINGLES

The cut for shingles is the same as the cheek cut of the jack-rafters.

## OCTAGONAL ROOF

The figure 13 is to the octagonal roof what the figure 17 is to the rectangular roof.

**Common Rafters.**—The length and foot- and plumb-cuts of common rafters are obtained in the same manner as described for pitch roofs.

**Hip Rafters.**—There are several methods of obtaining the lengths of the hips in an octagonal roof.

*First Method.*—Multiply the bridge measure of 13 in. and the rise per foot of run, in inches, of the common rafter by the total run, in feet, of the common rafter. For example, if the roof has a rise of 16 in. in 12 in., measure the bridge measure of 13 in. and 16 in., which is found to be $20\frac{7}{12}$ in. If the run of the common rafter is 10 ft., the total length of the hip will be $10\times20\frac{7}{12}=205\frac{10}{12}$ in. = 17 ft. $1\frac{10}{12}$ in.

*Second Method.*—Add 1 in. to every foot of run of the common rafter. Take this distance on the tongue, and the total rise on the body, calling the feet inches, and obtain the bridge measure, calling the inches feet. For example, the run of common rafter is 10 ft., adding 1 in. to every foot gives 10 ft, 10 in. The total rise is 13 ft. 4 in. Considering these as inches and taking the bridge measure, the result is $17\frac{2}{12}$ in., nearly. Calling the inches feet, the length of the hip is 17 ft. 2 in.

**Cuts of Hip Rafters.**—The foot-cut is found by using 13 in. on the tongue and the rise of the common rafter per foot of run on the body and cutting along the tongue. The plumb-cut is obtained by taking 13 in. on the tongue and the length

of the common rafter per foot of run on the body, and cutting along the body.

There are several ways of framing the tops of octagonal hips and the side cut therefore depends on the method used. When all the hip rafters meet at a point and are not backed, take 5.38 in., or $5\frac{3}{8}$ in. on the tongue of the square, and the length of hip per foot of run on the body and cut along the body. When the hips are backed, take 4.97 in., or 5 in. on the tongue and the length of the common rafter per foot of run on the body and cut along the body.

When the upper ends of two hips butt together and the two hips at right angles to these butt against their sides, these four hips have square cuts on the top. The other four hips are framed into the angles formed by the first four and have cheek cuts on both sides. To obtain these cheek cuts when the hips are not backed, take 13 in. on the tongue of the square and the length of the hip per foot of run on the body and cut along the body. When the hips are backed, take 5 in. on the tongue and the length of the common rafter per foot of run on the body and mark along the body; then apply the square to this mark, using the same figures and cut along the body.

**Jack-Rafters.**—To obtain the difference in lengths of jack-rafters in any octagonal roof use the following proportions: 5, or 4.97 in. is to the length of the common rafter per foot of run, as the spacing, in inches, is to the difference in length. Thus, the length of the common rafter per foot of run in a 16-in. pitch is 20 in. If the jack-rafters are spaced 16 in. on centers, the difference in length will be, $4.97 : 20 = 16 : 64.4$. That is, the first jack-rafter next to the common rafter will be 64.4 in. shorter than the common rafter, the second jack-rafter will be 64.4 in. shorter than the first jack-rafter, and so on.

Another method of obtaining this difference is to multiply the length of the common rafter per foot of run by .201 and then by the spacing in inches. Thus, $20 \times .201 \times 16 = 64.32$ in.

The foot- and plumb-cuts are the same as for the common rafter.

The side cut is found by taking 5 in. on the tongue of the square and the length of the common rafter per foot of run on the body and cutting along the body.

# PLUMBING

## SANITARY MAXIMS

1. General water-closet accommodation should never be placed in cellar or basement, but should be located where plenty of daylight and ventilation can be obtained, and should open to the outer atmosphere either direct, or by air-shafts at least 3 ft. square.

2. To prevent damp cellars, subsoil drains should be employed where necessary. They must be effectively trapped from sewers or house drains, and some means must be employed to maintain a seal. A check-valve, or back-water trap should be used to prevent a back discharge of sewage into them, should the drains become choked.

3. The arrangement of all drainage or vent pipes should be as direct as possible.

4. If there is a sewer in a street, every building should connect to it separately.

5. Where the soil is natural, the house sewer may be of vitrified earthenware pipe, uniformly bedded and jointed with Portland cement and clean sand. This pipe must run straight and must have a clear bore.

6. If the soil is filled in or made, the house sewer must be of extra-heavy cast iron, asphalt-coated; of wrought iron, galvanized and asphalt-coated; or of brass pipes, to avoid leakage by a settlement of the earth.

7. When it is necessary to run a private sewer to connect with a sewer in another street, it should be laid outside the curb of the street that the buildings face, not across lots where buildings may later be erected.

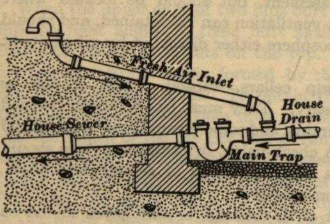
8. The main house drains should be run above the cellar floor when possible, and be secured against the cellar walls, supported upon piers built under each joint, or suspended from the cellar ceiling by adjustable hangers.

9. If house drains must be run under the cellar floors, they should be laid in straight runs, and *clean-outs*, or inspection fittings, should be placed at each branch or change in direction.

10. All changes in direction should be made with curved pipes or Y branches and $\frac{1}{16}$ or $\frac{1}{8}$ bends.

11. Old sewers should never be employed for new buildings unless first examined and tested by the smoke machine.

12. All house-drainage systems should be disconnected from city sewers by means of a main disconnecting trap, as here shown.




If the sewage from a country building delivers into a sea, a river, or an open space, the main drain trap may often be advantageously omitted. A fresh-air inlet must always accompany a main drain trap.

13. Fresh-air inlet orifices must be at least 15 ft. from the nearest window or door, and no cold-air box for a furnace should be so placed as to draw air from them.

14. All vent outlets should discharge at least 2 ft. above the highest part of a roof ridge, coping, or light-shaft, and as far as possible away from the light-shaft and all water tanks.

15. Vent pipes above roofs must be 4 in. in diameter or larger, and no cowls or vent caps should be used.

16. Vent pipes passing up through a low roof, and within 30 ft. of any windows in taller adjoining buildings, should be extended to safe points above the higher roofs.

17. All drain, soil, waste, and vent pipes between the main disconnecting trap and the vent outlets must be clear and unobstructed by traps, check-valves, etc.

18. All house-drainage work should be as accessible as possible, being placed either on the faces of walls or in air-shafts. When placed in walls, they should be covered by movable pipe boards.

19. Every fixture in a building must be separately trapped close to each fixture, except where a sink and washtubs adjoin each other, in which case the waste pipe from the tubs may join the inlet side of the sink trap below the water seal.

20. All fixtures and other such traps in a building must be back-vented by a separate pipe, which may deliver into a special back-vent stack at a point about 2 or 3 in. below top of fixture, for tenement or apartment buildings, and at much higher points, if desired, for private-residence work, but in no case at points lower than bottoms of fixtures or bowls.

21. Where lead-waste or back-vent branches connect to cast-iron stacks, the connections must be made with heavy brass ferrules and wiped solder joints; if to wrought-iron or brass stacks, by means of brass-screwed solder nipples provided with a socket to receive the lead pipe and form a flush internal surface. All solder joints in a plumbing system should be wiped.

22. Special precaution should be taken to secure perfect joints between water-closet traps placed above the floor and the branch soil and vent pipes for same. Brass floor plates should be used for the floor connections. A smoke test is necessary to prove these joints. Back-vent horn or porcelain traps should not be permitted, as they soon break off. The best modern practice is to back-vent the soil-pipe waste close to the floor connection by means of a wiped or screwed joint.

23. Overflow pipes from all fixtures must connect to traps on house side of their seals.

24. All fixture safes should be properly graded to a special waste pipe, which must deliver openly at some point, such as a safe-waste sink in the cellar. The outlets of these pipes should be covered with light flap valves.

25. The sediment pipe from the kitchen boilers should not be connected on the outlet side of the sink or other trap.

26. A separate small tank or valve should be employed to flush every water closet, and in no case should any water closet or urinal be supplied directly from the street pressure pipes when there is any liability of a drawback in the street mains.

27. One water closet, at least, should be allowed for fifteen inmates of a building. Every story of a tenement should contain at least one water closet.

28. Drinking water should be drawn directly from the street mains. Tank water may be used for washing and bathing purposes.

29. House tanks should be made of wood, and if placed inside the building should be lined with sheet lead or tinned sheet copper.

30. Outside tanks may be circular and made of cedar staves or wrought iron. Overflow from such tanks should discharge on the roof.

31. Overflow pipes from inside tanks may deliver into an eaves gutter if available, or may be trapped and discharge into an open sink. No pipe connecting to a tank should deliver directly into the drainage system.

32. All rain-water leaders, area water boxes, and subsoil drains, must be trapped from the drainage system, and the seals maintained.

33. In all cases where water comes muddy from the mains, a straining filter should be located in the cellar, to filter all water in the building; muddy water clogs boilers, water-backs, and circulation pipes.

34. A special germ-proof filter is a very valuable addition, and should be placed at a convenient point, to supply water for drinking purposes.

35. Steam-exhaust, blow-off, or drip pipes should not deliver directly into a drainage system. Such water should deliver through a deep seal trap, and at a temperature not higher than 100° F.

36. No privy vaults or cesspools for sewage should be permitted in any place where water closets can be connected with a city sewer.

37. All privy vaults and cesspools should be frequently treated with small quantities of disinfectant, and should be cleaned out thoroughly and often.

38. All architects should see that every drainage system, when completed, is tested with smoke under a pressure of at least 1 in. water column, because the sanitary arrangements are seldom perfect when this final test is neglected.

## DEFINITIONS AND TRADE TERMS

A *soil stack* is a vertical line of pipe extending through the roof and receiving the discharge of one or more water closets.

A *waste stack* is a pipe extending through the roof, and receiving the discharge from any fixtures except water closets.

*Waste pipes* are pipes that carry the discharge from the fixtures to the soil stacks or drains.

*Vent stacks* are vertical lines of pipe extending up through the roof and ventilating a number of fixture traps or waste pipes on two or more floors.

*Vent pipes* are special pipes provided for ventilating the system of drainage or waste piping and for preventing siphonage and back pressure.

A *back-vent pipe* is a pipe connecting a trap with a vent stack or directly with the outer air.

A *trap* is a device through which liquids and particles of solid waste matter may freely pass, but which prevents the passage of air in either direction.

A *fresh-air inlet* is a pipe extending from the house side of the main drain trap to some point outdoors, where it is open to the atmosphere.

*Rain leaders*, or *conductors*, are pipes that conduct rain water from roofs to house drains, cisterns, or other places of discharge.

*Cesspools* are receptacles built underground to receive the drainage from a house system. *Leaching cesspools* are those from which the liquid sewage is allowed to soak into the surrounding earth. *Tight cesspools* are receptacles that retain all sewage matter, both liquid and solid, until the cesspool is full, when it must be pumped out or otherwise removed.

The term *house drain* is applied to that part of the main horizontal drain and its branches inside the walls of the building extending to and connecting with the house sewer.

The *house sewer* is that part of the main drain or sewer extending from the foundation wall of the building to its connection with the public sewer, private sewer, or cesspool.

A *private sewer* is a main sewer that was not constructed by or under the supervision of the city authorities; although it may be constructed in a public highway.

*Roughing-in* is the installation of the soil, waste, vent, and supply pipes from the points at which they enter a building, or through the walls or floors where the fixtures are to be set. In new buildings, this work is erected before the walls are lathed or the floors are laid.

*Finishing* is the setting up of the plumbing fixtures and the connecting of them to the soil, waste, and supply pipes.

**LEAST SIZE OF SOIL, WASTE, AND VENT PIPE**

| Name of Pipe | Diameter Inches |
|---|---|
| Main and branch soil pipes | 4 |
| Main waste pipe | 2 |
| Branch waste pipes for kitchen sinks | 2 |
| Soil pipe for water closets on five or more floors | 5 |
| Waste pipe for kitchen sinks on five or more floors | 3 |
| Bath or sink waste pipe | 1½ to 2 |
| Basin or urinal waste pipe | 1¼ to 1½ |
| Pantry-sink waste pipe | 1½ |
| Safe waste pipe | 1 to 1½ |
| Water-closet trap | 3¼ to 4 |
| Wash tubs, 1½-in. waste pipe and 2-in. trap for set of two tubs | 1½ to 2 |
| Waste pipe for a set of three or four tubs | 2 |
| Main vents and long branches | 2 |
| Water-closet vents on three or more floors | 3 |
| Vent pipe for other fixtures on less than seven floors | 2 |
| Vent pipe for fixtures on eight stories or less | 3 |
| Vent pipe for nine stories and less than sixteen | 4 |
| Vent pipe for sixteen stories and less than twenty-one | 5 |
| Vent pipe for twenty-one stories and over | 6 |
| Branch vents for traps larger than 2 in. | 2 |
| Branch vents for traps 2 in. or less | 1½ |

This work is done after the plastering is finished and the floors are laid.

*Solder joints* are joints in which the parts are joined together by soft solder.

*Brazed joints* are those in which the parts are joined or fused together by the use of a solder made of granulated yellow brass.

*Wiped joints* are those in which the solder is fused on the joints and wiped to a neat smooth finish with a wiping cloth.

A *flux* is a substance applied to joints to aid the solder in becoming properly fused to the metal, and in flowing into the crevices of the joints.

## INSPECTION AND TESTING OF DRAINAGE SYSTEMS

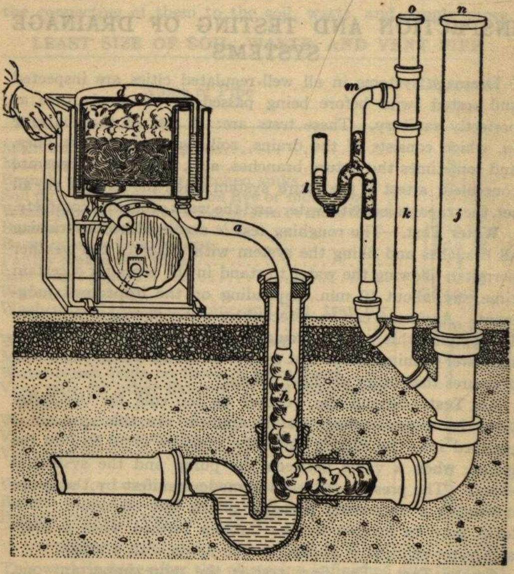
Drainage systems in all well-regulated cities are inspected and tested twice before being passed by the authorities as perfectly sanitary. These tests are: A test of the *roughing in*, which consists of the drains, soil, waste, and vent lines, and sometimes the fixture branches, also, before any pipes are concealed; a test of the entire system when the fixtures are all set, the traps sealed with water, and the work otherwise complete.

**Water Test.**—The roughing test is accomplished by closing all branches and filling the system with water (if the weather permits), allowing the water to stand in the pipes for a certain time, say, about 10 min., depending on the inspector's judgment. Any leaks can be detected by water flowing from them. In applying this test, particular care must be taken to use in the lower openings plugs that cannot be blown out by the heavy pressures that occur at these points.

**Air Test.**—Should the weather be too cold for the water test, the compressed-air test is applied. In this case air is pumped into the system until the pressure is 10 lb., by the gauge, when a valve between the pump and the system is closed. The presence of leaks is made manifest by the gauge indicating a decreasing pressure as the test continues. The leaks may be located by the bubbles formed when a soap-and-water solution is applied to the joints with a brush.

**Smoke Test.**—The final test is the more important one. The chief objects are to positively ascertain: if the system, when completed, is gas-tight; if the traps have perfect seals; if every part of the system is trapped that should be trapped; if any back-vent pipes are run into hollow partitions, attics, or chimneys. The final test commonly employed by leading sanitary authorities is known as the *smoke test*.

The principles involved in making a smoke test are shown by the accompanying illustration. The smoke machine is here connected by a rubber hose *a* to some pipes that are joined together for the purpose of illustrating the principles, and is composed of a double-action bellows *b* and a firebox, which




is shown, with fuel in it, at *c*. A water-jacket surrounds the firebox, and a cover or drum *d* is placed over the firebox so as to seal it by water in the jacket, as shown.

If the lever-handle *e* is moved sidewise, to and fro, air will be forced into the firebox through the pipe, which is provided with a three-way, lever-handle, shut-off cock *i*. The fuel in *c*,

being ignited at the bottom, burns upwards, and the air supplies the oxygen necessary for a slow and incomplete combustion of the mass. Smoke, consequently, is given off from the surface of the fuel (which should be greasy cotton waste) and is forced down through *a* into the drainage system.

Let the illustration represent a system of house drains, *f* being the main intercepting trap; *g*, the main house drain; *h*, the fresh-air inlet; *j*, the soil-pipe stack; *k*, the vent-pipe stack; *l*, the fixture trap; and *m*, its back-vent connection. To test the system with smoke, leave the tops of *k* and *j* open, and then blow dense smoke into the system. The smoke will fall down *h*, roll along *g*, and then rise up in each of the vertical pipe lines and so push the air ahead of it and out through the open ends on top. When the air is all out, and the smoke consequently blows freely from the open ends in dense, heavy clouds, the ends are sealed air-tight by laying in putty a 6-lb. sheet-lead cap over each, as shown at *n* and *o*. The bellows is operated until a pressure is raised in the soil pipes when the drum will rise and float in the water. The pressure required to raise the drum is equal to that required to support a column of water about 1 in. high. In the illustration, the drum is floating, a pressure of 1 in. water column is on the system, and the cock *i* is closed, to prevent the smoke escaping into the bellows. The effect of the pressure is also observed on the water in the traps *l* and *f*.

If any leaks are present in the system, they can be detected by smoke flowing from them; if everything is air-tight the drum will continue to float.

If the drum shows no appreciable fall in about 5 or 10 min., the system may be passed as gas-tight.

If the trap seals are not forced with any pressure less than that required to raise the drum, the traps may be passed as being safely sealed.

The smoke machine may be applied to the fresh-air inlet; or to one of the vent pipes above the roof—preferably to the latter, as any smoke that escapes while lighting the fuel cannot enter the building.

Porcelain water closets, particularly those of the siphon-jet type, frequently have kiln cracks and other flaws in the inside

walls, and sewer gas will escape through these into the building. The smoke test will reveal these leaks, by smoke flowing into the closet bowls through the flushing rims. Many closets otherwise perfect have these internal leaks.

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## WATER SUPPLY AND DISTRIBUTION

**Street Service.**—House pipes should connect to the mains by *corporation stops*. A stop and waste should always be placed under the sidewalk at the curb, and also a separate stop and waste upon the service pipe just inside the cellar wall.

If the street pressure is great enough to force water to the top floor of a building, all fixtures are usually supplied with both hot and cold water, by street pressure. If the pressure

**SIZES OF WATER PIPES IN BUILDINGS**

| Supply Branches | Low Pressure Inches | High Pressure Inches |
|---|---|---|
| To bath cocks | $\frac{3}{4}$ to 1 | $\frac{1}{2}$ to $\frac{3}{4}$ |
| To basin cocks | $\frac{1}{2}$ | $\frac{3}{8}$ to $\frac{1}{2}$ |
| To water-closet flush tank | $\frac{1}{2}$ | $\frac{1}{2}$ |
| To water-closet flush valve | 1 to $1\frac{1}{4}$ | $\frac{3}{4}$ to 1 |
| To water-closet flush pipes | $1\frac{1}{4}$ to $1\frac{1}{2}$ | |
| To sitz or foot baths | $\frac{1}{2}$ to $\frac{3}{4}$ | $\frac{1}{2}$ |
| To kitchen sinks | $\frac{5}{8}$ to $\frac{3}{4}$ | $\frac{1}{2}$ to $\frac{5}{8}$ |
| To pantry sinks | $\frac{1}{2}$ | $\frac{3}{8}$ to $\frac{1}{2}$ |
| To slop sinks | $\frac{5}{8}$ to $\frac{3}{4}$ | $\frac{1}{2}$ to $\frac{5}{8}$ |
| To urinals | $\frac{5}{8}$ to $\frac{3}{4}$ | $\frac{1}{2}$ to $\frac{5}{8}$ |

is too low, or the supply intermittent, a tank is placed in the attic to supply the building. If the pressure is too high, it is customary to apply a pressure regulator in the cellar.

The sizes of street service pipes depend chiefly on the street pressure and the size of building to be supplied. The common practice is given in the accompanying tables. When the pressure is low, the sizes of the street service pipes should be increased one size.

A safe rule is to allow a 40-gal. boiler for a building having one bathroom, and add 30 gal. capacity for every additional bathroom.

## SIZES OF STREET SERVICE PIPES

| Class of Building | Size of Pipe Inches |
|---|---|
| Single dwellings, 2 or 3 stories high | $\frac{3}{4}$ or 1 |
| Larger dwellings | 1 or $1\frac{1}{4}$ |
| Tenement buildings and apartment houses | $1\frac{1}{2}$ or 2 |
| Hotels and factories | 2 and up |

Size of water-closet compartments, minimum, 2 ft. 4 in. × 4 ft.

Size of water closets: Width of bowl over all, 13 in.; height of seat from floor, 17 in.; depth from wall to front of seat, 23 in.

## STANDARD SIZES OF GALVANIZED BOILERS

| Capacity Gallons | Length Feet | Diameter Inches | Capacity Gallons | Length Feet | Diameter Inches |
|---|---|---|---|---|---|
| 18 | 3 | 12 | 48 | 6 | 14 |
| 21 | $3\frac{1}{2}$ | 12 | 52 | 5 | 16 |
| 24 | 4 | 12 | 53 | 4 | 18 |
| 24 | 3 | 14 | 63 | 6 | 16 |
| 27 | $4\frac{1}{2}$ | 12 | 66 | 5 | 18 |
| 28 | $3\frac{1}{2}$ | 14 | 79 | 6 | 18 |
| 30 | 5 | 12 | 82 | 5 | 20 |
| 32 | 4 | 14 | 98 | 6 | 20 |
| 35 | 5 | 13 | 100 | 5 | 22 |
| 36 | 6 | 12 | 120 | 6 | 22 |
| 36 | $4\frac{1}{2}$ | 14 | 120 | 5 | 24 |
| 40 | 5 | 14 | 144 | 6 | 24 |
| 42 | 4 | 16 | 168 | 7 | 24 |
| 47 | $4\frac{1}{2}$ | 16 | 182 | 8 | 24 |

Size of urinals: Compartments, minimum, 24 in.×20 in.; partition, minimum, 4 ft. 6 in. high; height from floor to lip of urinal for men, 2 ft.; for boys, 1 ft. 2 in.

Size of bathtubs: Length, 4 ft. 6 in.; 5 ft.; 5 ft. 6 in.; 6 ft.; width, 30 in. to 35½ in.; depth, about 18 in.; height from floor to top of rim of tub, 24 in.; allow for outside connections at foot or side, 6 in.

## SIZES OF COPPER PANTRY SINKS

| Width Inches | Length Inches | Depth Inches | Width Inches | Length Inches | Depth Inches |
|---|---|---|---|---|---|
| 12 | 18 | 5 to 6 | 14 | 24 | 5 to 6 |
| 12 | 20 | 5 to 6 | 16 | 24 | 5 to 6 |
| 14 | 16 | 5 to 6 | 16 | 30 | 5 to 6 |
| 14 | 20 | 5 to 6 | 18 | 30 | 5 to 6 |

Size of wash basins: round bowls, 10 in, 12 in., 13 in., 14 in., 15 in., 16 in., 17 in., 18 in., and 20 in. in diameter; oval, 14 in.×17 in., 15 in.×19 in, and 16 in.×21 in.

Porcelain sinks can be had with a plain top or roll rim. Copper pantry sinks are made in either square or oval patterns; the former has a flat, and the latter, a round bottom. Sizes for both patterns are given in the table.

## SIZES OF CAST-IRON SLOP SINKS

| Length Inches | Width Inches | Depth Inches | Length Inches | Width Inches | Depth Inches |
|---|---|---|---|---|---|
| 16 | 16 | 10 | 36 | 21 | 12 |
| 20 | 14 | 12 | 23 | 15 | 15 |
| 20 | 16 | 12 | 36 | 21 | 16 |
| 22 | 18 | 12 | 48 | 20 | 12 |
| 24 | 20 | 12 | 48 | 20 | 17 |
| 30 | 20 | 12 | 60 | 20 | 12 |
| 36 | 18 | 12 | | | |

Pantry and kitchen sinks should be set 2 ft. 6 in. or 2 ft. 7 in. from the floor to the top of the cap. Slop sinks can be had with or without overflow and plug. These sinks should be set at such a height that the rim will be not more than 24 in. from the floor.

A sink should be located near a window for light, near the pantry or dining room for convenience, and away from the stove for comfort.

**SIZES OF PORCELAIN SINKS**

| Length Inches | Width Inches | Depth Inches |
|---|---|---|
| 30 | 24 | 7 |
| 36 | 23 | 7 |
| 42 | 24 | 7 |
| 48 | 24 | 7 |
| 28 | 18 | 9 |
| 30 | 20 | 9 |

**SIZES OF EARTHENWARE PANTRY SINKS**

| Length Inches | Width Inches | Depth Inches |
|---|---|---|
| 20 | 14 | 4½ |
| 23 | 16 | 5½ |
| 25 | 17 | 5½ |

### LAUNDRY TUBS

Laundry tubs, generally speaking, are made of slate, cement, soapstone, glazed earthenware, or solid porcelain. Wood, castiron, or sheet steel are not suitable materials for wash tubs. Tubs used in tenement and apartment houses should be provided with overflows. The height of wash tubs from floor to top of rim is from 32 to 36 in. The wringer should be set on the right-hand tub. Earthenware and porcelain tubs come separately, and are connected up singly or in sets of 2, 3, or 4, as required. They are made in two sizes, Nos. 1 and 2.

The accompanying tables give the average sizes of slate, cement, earthenware, and porcelain tubs:

**SLATE TUBS**

| Number of Parts | Length Inches | Width Inches | Depth Inches |
|---|---|---|---|
| 1 | 24 | 24 | 16 |
| 2 | 48 | 21 | 16 |
| 2 | 54 | 24 | 16 |
| 3 | 78 | 24 | 16 |

### CEMENT TUBS

| Number of Parts | Length Inches | Width Inches | Depth Inches |
|---|---|---|---|
| 2 | 48 | 21 or 24 | 16 |
| 2 | 53 | 24 | 16 |
| 2 | 60 | 24 | 16 |
| 3 | 72 | 21 or 24 | 16 |
| 3 | 80 | 24 | 16 |
| 3 | 90 | 24 | 16 |

### EARTHENWARE AND PORCELAIN TUBS

| Dimensions | No. 1 | | No. 2 | |
|---|---|---|---|---|
| | Feet | Inches | Feet | Inches |
| Length for each tub............ | 2 | 0 | 2 | 7½ |
| Length required for two tubs.... | 4 | 1 | 5 | 4 |
| Length required for three tubs.. | 6 | 2 | 8 | 0 |
| Length required for four tubs... | 8 | 3 | 10 | 9 |
| Width from front to back....... | 2 | 3 | 2 | 3 |
| Depth inside.................. | 1 | 3 | 1 | 3 |

# HEATING

## STEAM HEATING

A steam-heating system, with steam having a pressure less than 10 lb. by the gauge, is called a *low-pressure* system. If the steam is at a higher pressure, the system is called *high-pressure* system. When the water of condensation flows back to the boiler by gravity alone, the apparatus is known as a *gravity-circulating* system. When the boiler is run at a high, and the heating system at a low, pressure, the condensed steam must be returned to the boiler by a pump, steam return trap, or injector.

The low-pressure gravity circulating systems considered to be the best are: the two-pipe system with wet returns; the two-pipe system with dry returns; the one-pipe system, in which all mains, branches, and risers are relieved into a return main below the water-line; and the one-pipe circuit system, in which all pipes are run above the water-line. The choice of any system will depend on special conditions and requirements.

**Radiation.**—To find the amount of direct radiating surface required to heat a room, basing calculations upon its cubic contents, allow 1 sq. ft. direct radiating surface to the number of cubic feet shown in the acccompanying table.

**PROPORTION OF RADIATING SURFACE TO VOLUME OF ROOM**

| Description | Volume of Room Cubic Feet |
|---|---|
| Bathrooms or living rooms, with two or three exposures and large amount of glass surface... | 40 |
| Living rooms one or two exposures with large amount of glass surface.................. | 50 |
| Sleeping rooms.............................. | 55 to 70 |
| Halls.......................................... | 50 to 70 |
| Schoolrooms.................................. | 60 to 80 |
| Large churches and auditoriums.............. | 65 to 100 |
| Lofts, workshops, and factories............... | 75 to 150 |

The ratios here given will produce reasonably good results in ordinary work, if the engineer uses proper judgment in allowing for exposures, leakages through building, etc.

**Proportion of Radiating Surface to Glass Surface.**—In proportioning the radiating surface to the glass surface *Baldwin's* rule* is generally used. This rule is as follows:

**Rule.**—*Divide the difference in temperature between that at which the room is to be kept and the coldest outside atmosphere, by the difference between the temperature of the steam pipes and that at which the room is to be kept. The quotient will be the*

*This rule also applies to hot-water heating.

*square feet or fraction thereof of plate or pipe surface to each square foot of glass, or its equivalent in wall surface.*

Let $S$ = amount of radiating surface required to counteract cooling effect of glass and its equivalent in exposed wall surface in square feet;

$t$ = difference in degrees Fahrenheit between desired temperature of room and that of external air;

$t_1$ = difference in degrees Fahrenheit between temperature of heating surface and that of air in room;

$s$ = number of square feet of glass and its equivalent in exposed wall surface.

Then,
$$S = \frac{t}{t_1} s$$

The heating surface found by this rule only compensates for the heat lost by transmission through windows, walls, and other cooling surfaces; it does not provide for cold air entering the room through loosely fitting doors, windows, etc., for which an ample allowance must be made. Some buildings are so poorly constructed that 50% or more must be added to the amount of heating surface obtained by the rule in order to counteract the cooling effect of these air leakages. A common practice is to add 25% for buildings of ordinary good construction. Ample allowance should be made for rooms exposed to cold winds. It is usual to estimate about 10 sq. ft. of wall surface as equivalent in cooling power to 1 sq. ft. of glass.

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## HOT-WATER HEATING

The circulation in a hot-water heating system is a movement of hot water from the boiler to the radiators, where it parts with some heat, and a consequent movement of colder water from the radiators to the boiler to become reheated. Without circulation heat cannot be conveyed from the boiler to the radiators. The velocity of circulation depends chiefly on: the difference between the mean density of the ascending current and that of the returning current; the vertical height of circuit above the boiler; and the resistance to flow due to friction, change in direction, etc. The theoretical velocity

could easily be computed, but, as it is only imaginary, it is of little value to the practical man; and, further, the actual velocity bears no definite ratio to the theoretical.

**Radiating Surface.**—The sizes of pipes should be governed by the amount of radiating surface to be supplied, the height of the radiators above the boiler, and the number of changes in the direction of the several currents. It is considered safe practice to allow from 50 to 100 sq. ft. of direct radiation for each square inch of cross-section in the pipe. If the pipes are short, straight, and high, 1 to 100 would be allowed; if long, crooked, or low, 1 to 50 or more, according to the conditions.

**RATIO OF HOT-WATER RADIATING SURFACE TO VOLUME OF ROOM**

| Name of Room | Ratio 1 Sq. Ft. to Cu. Ft. |
|---|---|
| Living rooms, one side exposed | 30 |
| Living rooms, two sides exposed | 28 |
| Living rooms, three sides exposed | 25 |
| Sleeping rooms | 30 to 40 |
| Hall and bathrooms | 20 to 30 |
| Schoolrooms and offices | 30 to 50 |
| Factories and stores | 50 to 70 |
| Auditoriums and churches | 80 to 100 |

To determine the amount of radiating surface necessary to warm a building easily in all kinds of weather, and to proportion it so that each room will have the required temperature at the same time, are very important points, requiring careful consideration. No rules can be given applicable to all cases, but for ordinary buildings having the average wall and glass exposures, the accompanying table is found in practice to give good results, when used with judgment. It is for direct radiation and the average temperature in the radiators is 160° F.

For direct-indirect radiation, allow at least 25% extra; for indirect radiation allow 50% extra. Due allowance must be made for leakages through loose doors, windows, etc.

## FURNACE HEATING

It is assumed in the accompanying rules and tables that the average temperature of the hot air in the flues is about 120°, and that the air is moved solely by natural draft.

A simple method for proportioning hot-air pipes to deliver a given volume of air to the several floors is to assume that 1 sq. in. of stack, or flue, area will supply 100 cu. ft. of air per hour at the first floor, 125 cu. ft. at the second floor, and 150 cu. ft. at the third floor. The accompanying table may be used in calculating the area of hot-air pipes; but a more accurate method is given in the following rule:

### RATIO OF AREA OF HOT-AIR PIPES TO VOLUME OF ROOM

| Rooms | Ratio 1 Sq. In. to Cu. Ft. |
|---|---|
| First-floor rooms, moderate exposure | 30 |
| First-floor rooms, great exposure | 20 to 25 |
| Second-floor rooms | 25 to 35 |
| Third-floor rooms | 30 to 40 |

**Rule.**—*For rooms on the first floor, add together the total glass surface and one-fourth the area of the exposed walls, in square feet, and multiply the total by 1.5; the product is the proper area of the pipe, in square inches. For second-story rooms, multiply by 1 to 1.25, according to the exposure; and for the third story, by .75 to 1.*

If leaders are of considerable length, their area should be about one-fourth greater than the connecting stacks.

# ESTIMATING

## APPROXIMATE ESTIMATES

The accompanying table shows the approximate cost per cubic foot of various kinds of structures. In computing the contents of a building there is no uniformity in practice, but no great error will be made in figuring the solid contents from floor of cellar to ridge of roof.

### COST OF BUILDINGS PER CUBIC FOOT

| Class of Building | Cost per Cubic Foot Cents |
|---|---|
| Small frame buildings, costing from $800 to $1,500 | 10 to 12 |
| Frame houses, 8 to 12 rooms, costing from $1,500 to $10,000 | 12 to 15 |
| Brick houses, 8 to 10 rooms | 15 to 18 |
| Highly finished city dwellings, brick or stone | 20 to 25 |
| Schoolhouses, brick | 15 to 20 |
| Churches, stone | 20 to 40 |
| Office buildings, well finished | 35 to 50 |
| Hospitals, libraries, and hotels | 35 to 50 |

## STONEWORK

### INTRODUCTION

Stone masonry is usually measured by the perch; in some sections of the country, however, measurement by the cord is preferred, but the best method (as being invariable) is by the cubic yard. In estimating by the perch, it should be stated how much the perch is taken at, whether $24\frac{3}{4}$ or 25 cu. ft. Note should also be made in regard to deduction for openings, as in most localities it is not customary to deduct those under a certain size, and corners are usually measured twice.

Rough stone from the quarry is usually sold under two classifications, namely, rubble and dimension stone. *Rubble* consists of pieces of irregular size, such as are most easily obtained from the quarry, up to 12 in. in thickness by 24 in. in length. Stone ordered of a certain size, or to square over 24 in. each way and to be of a particular thickness, is called *dimension stone.*

Rubble masonry and stone backing are generally figured by the perch or the cubic yard. Dimension-stone footings are measured by the square foot unless they are built of large irregular stone, in which case they are measured the same as rubble. Ashlar work is always figured by the superficial foot; openings are usually deducted and the jambs are measured in with the face work. Flagging and slabs of all kinds, such as hearths, treads for steps, etc., are measured by the square foot; sills, lintels, moldings, belt-courses, and cornices, by the linear foot, and irregular pieces are generally figured by the cubic foot. All carved work is done at an agreed price by the piece.

## METHODS OF ESTIMATING MASONRY

The following proportions and cost of materials, and amount of labor required for the classes of work below specified, are reasonably accurate, and will serve to give a good idea of how to estimate such work.

### Cost of Rubble Masonry per Perch

*Using 1-to-3 Lime Mortar*

| | |
|---|---|
| 1 perch stone (25 cu. ft.) delivered at work | $1.75 |
| ¾ bu. lime, @ .23 per bu. | .17¼ |
| ⅕ T. of sand, @ $1.35 per ton | .27 |
| ⅓ da. mason's labor, @ $4 per da | 1.33⅓ |
| ⅙ da. helper's labor, @ $2.20 per da | .36⅔ |
| Total | $3.89¼ |

*Using 1-to-3 Portland Cement Mortar*

| | |
|---|---|
| 1 perch stone | $1.75 |
| ½ bbl. Portland cement, @ $1.25 per bbl | .62½ |
| ⅓ T. sand, @ $1.35 per T. | .45 |
| ⅓ da. mason's labor, @ $4 per da | 1.33⅓ |
| ⅙ da. helper's labor, @ $2.20 per da | .36⅔ |
| Total | $4.52½ |

### Cost of 1 Sq. Ft. of Bluestone Facing or Ashlar

| | |
|---|---|
| Cost of stone | $.40 |
| Mortar | .01 |
| Mason's time | .08 |
| Laborer's time | .02½ |
| Cutting and fitting | .12 |
| Total | $.63½ |

### Cost of 1 Cu. Yd. of Concrete

*1 Cement, 3 Sand, and 6 Broken Stone*

| | |
|---|---|
| 1 bbl. of Portland cement, @ $1.25 | $1.25 |
| ½ T. of sand, @ $1.35 | .67½ |
| 1 cu. yd. (about 6 bbl.) broken stone, @ $2.00 | 2.00 |
| Laborer ½ da., @ $2.00 | 1.00 |
| Total | $4.92½ |

### Cost of 1 Sq. Yd. of Cellar Floor

*4-in. Concrete Base and 1-in. Cement Finish*

| | |
|---|---|
| ⅔ bag Portland cement, @ .31¼ | $.21 |
| ⅛ T. of sand, @ $1.35 | .17 |
| ⅑ cu. yd. stone, @ $2.00 | .22 |
| Labor | .15 |
| Finishing surface | .10 |
| Total | $.85 |

## DATA ON ASHLAR AND CUT STONE

**Cost.**—The following figures are average prices of stone when the transportation charges are not excessive; the figures are not given as fixed values, but to show the relative costs. They are based on quarrymen's wages of $2.20 per da., and stone cutters' of $4 per da.

Good rock-face bluestone ashlar, with from 6-in. to 10-in. beds, dressed about 3 in. from face, will cost, ready for laying, from 30 to 40c. per sq. ft., face measure; while very good work will cost from 40 to 55c. per sq. ft. Regular coursed bluestone ashlar, 12 to 18 in. high, with from 8-in. to 12-in. beds, will cost about 50c. per sq. ft. To this (and the previous figures) must be added the cost of hauling, which on an average will be about 3c. per sq. ft. The cost of setting ashlar may be taken at about 10c. per sq. ft.

The rough stock for dimension stone will cost, at the quarry, if Quincy granite, in pieces of 1 cu. yd., or less, from 50 to 75c. per cu. ft.; if bluestone, about 50c.; if Ohio sandstone, about 30c. per cu. ft.; if Indiana limestone, about 25c. per cu. ft.; and if Lake Superior redstone, about 40c. per cu. ft.

Flagstones for sidewalks, ordinary stock, natural surface, 3 in. thick, with joints pitched to line, in lengths (along walk) from 3 to 5 ft., will cost, for 3 ft. walk, about 11c. per sq. ft. (if 2 in. thick, 10½c.); for 4 ft. walk, 12c.; and for 5 ft. walk, 16c. per sq. ft. The cost of laying all sizes will average about 3c. per sq. ft. The foregoing figures do not include cost of hauling.

Curbing (4″×24″ granite) will cost, at quarry, from 40 to 50c. per lin. ft.; digging and setting will cost from 10 to 12c. additional; the cost of freight and hauling must also be added.

The following figures show the approximate cost of cut bluestone for various uses:

| | |
|---|---|
| Flagstone, 5 in., size 8 ft.×10 ft., edges and top bush-hammered, per square foot, face measure | $.75 |
| Flagstone, 4 in., size 5 ft.×5 ft., select stock, edges clean cut, natural top, per square foot | .45 |
| Door sills, 8 in.×12 in., clean cut, per linear foot | 1.35 |
| Window sills, 5 in.×12 in., clean cut, per linear foot | .80 |
| Window sills, 4 in.×8 in., clean cut, per linear foot | .45 |
| Window sills, 5 in.×8 in., clean cut, per linear foot | .60 |
| Lintels, 4 in.×10 in., clean cut, per linear foot | .65 |
| Lintels, 8 in.×12 in., clean cut, per linear foot | 1.25 |
| Water-table, 8 in.×12 in., clean cut, per linear foot | 1.25 |
| Coping, 4 in.×21 in., clean cut, per linear foot | 1.20 |
| Coping, 4 in.×21 in., rock-face edges and top, per linear foot | .50 |
| Coping, 3 in.×15 in., rock-face edges and top, per linear foot | .35 |
| Coping, 3 in.×18 in., rock-face edges and top, per linear foot | .40 |
| Steps, sawed stock, 7 in.×14 in., per linear foot | 1.10 |
| Platform, 6 in. thick, per square foot | .50 |

To the prices of cut stone given must be added the cost of setting, which, for water-tables, steps, etc., will be about 10c. per lin. ft., and, for window sills, etc., about 5c. per lin. ft.

In addition, allow about 10c. per cu. ft. for fitting, and about 5c. per cu. ft. for trimming the joints after the pieces are set in place.

A stone cutter can cut about 4 sq. ft. of granite per da., 6 sq. ft. of bluestone, and about 8 sq. ft. of Ohio sandstone or Indiana limestone. These figures are for 6-cut patent-hammered work. For rock-face ashlar (beds worked about 3 in. from face, the rest pitched), a workman can dress from 15 to 25 sq. ft. of random ashlar per da., and from 18 to 20 sq. ft. of coursed ashlar. In dressing laminated stone, from two to three times more work in a day can be done on the natural surface than on the edge of layers. In figuring cut stone, an ample allowance should be made for waste, which, on an average, will be 15%.

## BRICKWORK

### GENERAL REMARKS

Brickwork is generally estimated by the thousand brick laid in the wall, but measurements by the cubic yard and by the perch are also used. The following data will be useful in calculating the number of brick in a wall. For each superficial foot of wall, 4 in. (the width of 1 brick) in thickness, allow $7\frac{1}{2}$ brick; for a 9-in. (the width of 2 brick) wall, allow 15 brick; for a 13-in. (the width of 3 brick) wall, allow $22\frac{1}{2}$ brick; and so on, estimating $7\frac{1}{2}$ brick for each additional 4 in. in thickness of wall. In large buildings with thick walls, 21 brick or even 20 brick per cu. ft. may be allowed, especially where there are many openings, which are counted as solid wall. The preceding figures are for brick about $8\frac{1}{4} \times 4 \times 2\frac{1}{4}$ in. in size. If smaller brick are used, the figures will be increased proportionately. As brick vary considerably, a minimum size should be specified, when a large number are bought; otherwise many more will be required than were figured on. If brickwork is estimated by the cubic yard, allow 500 brick to a yard. This figure is based on the use of the size of brick just given, with mortar joints not over $\frac{3}{8}$ in. thick. If the joints are $\frac{1}{8}$ in. thick, as in face brickwork, 1 cu. yd. will require about 575 brick. In making calculations of the number of

brick required, an allowance of, say, 5% should be made for waste in breakage, etc.

The practice in regard to deductions for openings is not uniform throughout the United States, but small openings are usually counted solid, as the cost of extra labor and the waste in working around these places balances that of the brickwork saved. All large openings, 80 sq. ft. or over in area, should be deducted.

When openings are measured solid, it is not usual to allow extra compensation for arches, pilasters, corbels, etc. Rubbed and ornamental brickwork should be measured separately, and charged for at a special rate.

## DATA ON BRICKWORK

The following estimates on the cost of brickwork are very carefully compiled, and will be found trustworthy. It is to be understood that the prices will vary with the cost of materials and labor; but the proportions will be constant. The figures are based on *kiln*, or actual, count—that is, with deductions for openings. When the work is measured with no deductions, the cost per thousand may be assumed as about 15% less than the prices given, which are exclusive of scaffolding, hoisting, and builder's profit.

Cost of Common Brickwork per Thousand Brick

*Using 1-to-3 Lime Mortar*

| | |
|---|---|
| 1,000 brick | $8.00 |
| 2 bu. lump lime, at $.23 per bu. | .46 |
| ½ T. sand, at $1.35 per T | .67½ |
| 8 hr., bricklayer, at $.60 per hr | 4.80 |
| 5 hr., laborer, at $.27½ per hr | 1.37½ |
| Total | $15.31 |

*Using 1-to-3 Portland Cement Mortar*

| | |
|---|---|
| 1,000 brick | $8.00 |
| 1 bbl. Portland cement, at $1.25 per bbl | 1.25 |
| ⅗ T. sand, at $1.35 per T | .81 |
| 8 hr., bricklayer, at $.60 per hr | 4.80 |
| 5 hr., laborer, at $.27½ per hr | 1.37½ |
| Total | $16.23½ |

*Using 1-to-4 Lime-and-Cement Mortar*

| | |
|---|---|
| 1,000 brick | $8.00 |
| ¾ bu. lime, at $.23 per bu | .17¼ |
| ½ T. sand, at $1.35 per T | .67½ |
| ⅔ bbl. cement, at $1.25 per bbl | .83⅓ |
| 8 hr., bricklayer, at $.60 per hr | 4.80 |
| 5 hr., laborer, at $.27½ per hr | 1.37½ |
| Total | $15.85 |

COST OF PRESSED BRICKWORK PER THOUSAND BRICK

*Using Lime Putty Mortar*

| | |
|---|---|
| 1,000 pressed brick, cost from $20 to $40, average | $30.00 |
| 1½ bu. lime, at $.23 | .34½ |
| ½ bbl. cement at $1.25 | .62½ |
| ½ T. fine sand, at $1.35 | .67½ |
| 24 hr., bricklayer, at $.60 per hr | 14.40 |
| 14 hr., laborer, at $.27½ per hr | 3.85 |
| Total | $49.89½ |

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## CARPENTRY

### ESTIMATING QUANTITIES

**Board Measure.**—Lumber used in framing is measured by the board foot, which is 12 in. × 12 in. × 1 in. Lumber is always sold on a basis of 1,000 ft. board measure, the customary abbreviation for the latter term is B. M., and for thousand is M; thus, 500 ft. board measure, costing $14 per thousand, would be written: 500 ft. B. M. at $14 per M.

To obtain the number of board feet in any piece of timber, the length of the scantling, in inches, may be multiplied by the end area, in square inches, and the result divided by 144. For example, the number of feet board measure in a floor joist 20 ft. long, 3 in. thick, and 10 in. deep, will be 240 in. (=20 ft.×12) multiplied by 30 sq. in. (the end area), or 7,200 sq. in., 1 in. thick; dividing by 144, the result is 50 ft. B. M.

The rule used by most contractors and lumber dealers is as follows:

**Rule.**—*Multiply the length, in feet, by the thickness and width in inches, and divide the product by* 12.

Thus, a scantling 26 ft. long, 2 in. thick, and 6 in. wide, contains $\frac{26\times2\times6}{12}=26$ ft. B. M. This rule, expressed in a slightly different manner more convenient for mental computation, is as follows:

**Rule.**—*Divide the product of the width and thickness, in inches, by 12, and multiply the quotient by the length, in feet.*

Thus, a $2''\times10''$ plank, 18 ft. long contains $\frac{2\times10}{12}\times18=30$ ft. B. M.

**Studs.**—To calculate the number of studs, set 16″ on centers, the following rule may be used:

**Rule.**—*From the length of the partition deduct one-fourth, and to this result add 1. Count the number of returns, or corners, on the plan, and add two studs for each return.*

The reason for adding 1 is to include the stud at the end which would otherwise be omitted. The sills, plates, and double studs must be measured separately. For example, the total number of studs required for the lengths of partitions given at the left is as follows: Deducting one-quarter of 60 ft. from it, the remainder is 45; adding 1 stud, the result is 46. If there are say, 4 returns, at 2 studs each, the total number is $46+8=54$ studs.

| |
|---|
| 30 ft. 6 in. |
| 10 ft. 6 in. |
| 9 ft. 6 in. |
| 5 ft. 0 in. |
| 4 ft. 6 in. |
| 60 ft. 0 in. |

As a general rule, when (as is usual) the studs are set at 16-in. centers, 1 stud for each foot in length of partition will be a sufficient allowance to include sills, plates, and double studs. Thus, if the total length of partitions is 75 ft., 75 studs will be sufficient for sills, double studs, etc. If the studs are set at 12-in centers, the number required will be equal to the number of feet in length of partition plus one-fourth. Thus, if the length of partitions is 72 ft., $72+18$, or 90 studs, will include those required for sills, plates, etc.

The same rules may be used for calculating the number of joists, rafters, tie-beams, etc.

A good way to estimate bridging is to allow 3c. apiece, or 6c. a pair; this will be sufficient to furnish and set a pair made of $2''\times3''$ spruce or hemlock stuff.

**Sheathing.**—To calculate sheathing or rough flooring (which is not matched), find the number of feet board measure required to cover the surface, making no deductions for door or window openings, for what is gained in openings is lost in waste. If the sheathing is laid horizontally, only the actual measurement is necessary, but, if it is laid diagonally, add 8 or 10% to the actual area. When the sheathing is matched or shiplapped, add from 5 to 15% to the actual area.

In sheathing roofs where many hips, valleys, roof dormers etc. occur, there will be a great deal of waste material caused by mitering the boards, fitting around cheeks of dormers and forming saddles behind chimneys. This waste is not readily calculated and must be determined by the actual conditions as well as by the care exercised by the men in utilizing the cuttings. In covering large areas a great deal of material can be saved by ordering the lengths of boards to suit the spacing of the rafters.

**Flooring.**—In estimating matched flooring, 1 sq. ft. of $\frac{13}{16}$-in. stuff is considered to be 1 ft. B. M. If the flooring is 3 in. or more in width, add one-quarter to the actual number of board feet, to allow for waste of material in forming the tongue and groove; if less than 3 in. wide, add one-third. Flooring of $1\frac{1}{8}$ in., finished thickness, is considered to be $1\frac{1}{4}$ in. thick; and for calculating it the surface measurement is increased 50%. (This consists of 25% for extra thickness over 1 in. and 25% for waste in tonguing and grooving.) To this amount 5% is added for waste in handling and fitting.

In figuring the area of floors, the openings for stairs, fireplaces, etc. should be deducted.

**Siding.**—Siding is usually measured by the superficial foot. No deduction should be made for ordinary window or door openings, as these usually balance the waste in cutting and fitting. Careful attention must be given to the allowance for lap. If 6-in. (nominal width, actual width $5\frac{5}{8}$ in.) siding, laid with 1-in. lap, is used, add one-quarter to the actual area, in order to obtain the number of square feet of siding required. If 4-in. stuff is used, add one-third to the actual area. When no allowance is made for openings, the corner and baseboards need not be figured separately.

**Cornices.**—Cornices may be measured by the running foot, the molded and plain members being taken separately. A good method of figuring cornices is as follows:

**Rule.**—*Measure the girth, or outline, and allow 1c. for each inch of girth, per linear foot.*

## QUANTITIES OF MATERIAL PUT IN PLACE PER DAY PER MAN

| Class of Material | Feet B. M. or Number | Remarks |
|---|---|---|
| Studding, 2″×4″, or 2″×6″ | 400 | Wall or partition |
| Rafters.................... | 400 | |
| Floor joists, 2″×10″ or 3″ ×12″.................. | 450 | |
| Sheathing, unmatched...... | 500 | Laid horizontally |
| Sheathing, unmatched...... | 400 | Laid diagonally |
| Sheathing, matched........ | 350 | Laid horizontally |
| Sheathing, matched........ | 275 | Laid diagonally |
| Sheathing, roof............ | 500 | Plain gable roof |
| Sheathing, roof............ | 300 | Much cut up by hips, valleys, dormers, etc. |
| Beveled siding, 6-in. wide... | 400 | Includes fitting and setting corner boards, base trim, and scaffolding |
| Posts and beams over cellar. | 300 to 400 | |
| Plaster grounds, linear feet, per man................ | 225 | For base and wainscot, leveled and straightened in good shape |
| Bridging, number of pairs, per hour, per man....... | 15 | Includes cutting and setting |
| False jambs around openings, per hour, per man... | 4 | |

This price will pay for material and for setting, the cost of the mill work being estimated at 50%, or ½c.

**Quantity of Material Set per Day.**—It is impossible to estimate exactly the quantity of material set per day, as it depends

on the skill of the artisan, his rapidity of working, the ease or difficulty of the work, besides numerous accidental circumstances. The subjoined figures, are only intended to give an idea of the relative quantities, and not as a standard to be adhered to in all cases. The estimates are based on an 8-hr. day, and wages of $3.80 per da. If the hours or pay be less or greater, the results will be correspondingly diminished or increased.

**Nails.**—To calculate the quantity of nails required in executing any portion of the work, the following table, based on the use of cut nails, will be found useful:

**TABLE FOR ESTIMATING QUANTITY OF NAILS**

| Material | Pounds Required | Name of Nail |
|---|---|---|
| 1,000 shingles | 5 | 4d. |
| 1,000 laths, 4 nails to 1 lath | 7 | 3d. fine |
| 1,000 sq. ft. of beveled siding | 18 | 6d |
| 1,000 sq. ft. of sheathing | 20 | 8d. |
| 1,000 sq. ft. of sheathing | 25 | 10d. |
| 1,000 sq. ft. of flooring | 30 | 8d. |
| 1,000 sq. ft. of flooring | 40 | 10d. |
| 1,000 sq. ft. of studding | 15 | 10d. |
| 1,000 sq. ft. of studding | 25 | 20d. |
| 1,000 sq. ft. of furring 1 in. × 2 in. | 10 | 10d. |
| 1,000 sq. ft. $\frac{7}{8}$-in. finished flooring | 20 | 8d. to 10d. finish |
| 1,000 sq. ft. $1\frac{1}{8}$-in. finished flooring | 30 | 10d. finish |

## ESTIMATING COSTS

The character of the work, which must be determined by the spirit and letter of the specifications, will be the controlling factor in fixing costs. In the case of material, where the requirements are exacting and demand a grade of material that can only be obtained by special selection, an extra rate must always be considered. This is best secured by contracting with the lumber merchants for the supply of the material to accord strictly with the architect's stipulation. The matter

of labor, however, is one on which too much care and forethought cannot be expended. What may be considered satisfactory work by one contractor would be considered inferior by another, and this often accounts for the great differences in estimates.

**Cost per Square Foot.**—For all classes of materials that enter into the general framing and covering of a building, a close estimate may be made by analyzing the cost per square foot of surface; that is, the cost of labor and materials—studs and sheathing in walls, joists and flooring in floors, etc.—required for a definite area should be closely determined, and this cost, divided by the area considered, will give the price per square foot. If the corresponding whole area is multiplied by the figure thus obtained, the result will be the cost of that portion of the work. While it is usual to adopt a uniform rate for the various grades of work, a careful analysis will show that roof sheathing in place costs more than wall sheathing owing to its position; and that the studs in walls and partitions cost more than floor joists, as they are lighter and therefore require more handling for equal amounts of material.

The following example shows how to determine the cost per square foot of flooring, and indicates the general method to be pursued in like cases. The area used in calculation is a square of 100 sq. ft. The cost of labor is estimated at 40% of that of the materials, which experience has shown to be a very close approximation to the actual cost of general carpenter work.

Cost of Finished Floor per Square

| | |
|---|---|
| Joists, hemlock, 8 pieces, 3 in. × 10 in. × 10 ft. = 200 ft. B. M. at $30 per M. | $6.00 |
| Bridging, hemlock, 7 sets, 2 in. × 3 in. × 1 ft. 4 in. = 4⅔ ft. B. M. at $30 per M. | .14 |
| Rough flooring, hemlock, ⅞ in. thick, laid diagonally, 100 ft. + 25 ft. + 10 ft. = 135 ft. B. M. at $28 per M. | 3.78 |
| Finished flooring, white pine, ⅞ in. thick, 125 ft. B. M. at $45 per M. | 5.63 |
| Nails, about 3 lb. at $2.50 per 100 lb. | .08 |
| Labor, 40% of cost of materials | 6.25 |
| Total cost for 100 sq. ft. | $21.88 |

Cost per square foot, 21.88 ÷ 100 = 22c, nearly.

A similar method may be followed in estimating the cost of interior finish, paneling, doors, etc.

**Cost per Thousand Feet.**—The following analysis shows the general method of estimating rough carpenter work:

COST OF 1,000 FT. B. M. OF HEMLOCK

*Including Framing*

| | |
|---|---|
| 1,000 ft. of hemlock.......................... | $30.00 |
| Nails and spikes, allowing 100 lb. to 3,000 ft. of lumber, at $2.50 per 100 lb.......................... | .84 |
| Labor, taking 50% of cost of material as cost of framing | 15.42 |
| Cost per thousand feet B. M.................. | $46.26 |

**COST OF MISCELLANEOUS ITEMS OF CARPENTRY**

| Class of Work | Cost | Remarks |
|---|---|---|
| Setting window frames in wooden buildings....... | $ .35 | Each |
| Furring brick walls 1″×2″ strips, 12-in. centers..... | .02½ | Per sq. ft.; includes labor, material, and nails |
| Furring brick walls, 1″×2″ strips, 16-in. centers..... | .02 | Per sq. ft. |
| Cutting holes and fitting plugs in brick walls..... | .05 | Each |
| Setting window frames in brickwork.............. | .60 | Each; includes nails and bracing |
| Door frames in brickwork | .60 | Each |
| Window frames in stonework.................. | 1.25 | Each; for ordinary work screeded and bedded |
| Window frames in stonework.................. | 2.00 | Each; for careful work |
| Door frames in stonework | 2.00 | Each; for careful work |
| Furnishing and setting trimmer-arch centers.... | 2.00 | Each |
| Arch centers, 3½-ft. span, 8-in. reveal............ | 1.50 | Each; includes supports and wedges |

# JOINERY

## ESTIMATING QUANTITIES

Joinery includes all the interior and exterior finish put in place after the framing and the covering are completed; as, for example, door and window frames, doors, baseboard, paneling, wainscoting, stairs, etc. Most of these materials are worked at the mill and brought to the building ready to set in place.

**Frames.**—In taking off door and window frames, describe and state sizes. Measure architraves by the running foot, giving width and thickness, whether molded or plain, and state the number of plinth and corner blocks.

**Sash.**—State dimensions of sash (giving the width first); thickness of material, molded or plain; style of check-rail and sill finish; thickness of sash bar, whether plain, single, or double hung; and sizes (giving dimensions in inches) and number of lights. Use standard sizes as much as possible.

**Doors.**—Describe and state the sizes and thickness of all doors, whether the framing is stuck-molded, raised-molded, or plain; and number of panels, whether plain or raised. Use stock sizes wherever possible and suitable.

**Blinds.**—Describe size and thickness of blinds, whether paneled or slatted (fixed or movable), molded or plain.

**Baseboard and Beam Casings.**—Measure baseboards and beam casings by the running foot, stating width and thickness of stuff, and whether molded or plain.

**Wainscoting.**—Measure wainscoting by the superficial foot. State kind of finish, whether paneled or plain, and style of molding and panels. Measure wainscoting cap and base by the running foot.

**Stairways.**—Stairways are generally taken by the contractor at so much per step, including everything complete according to the specifications. In measuring stairways, take off the amount of rough material in carriage timbers, and the planed lumber in treads, risers, and strings. Measure balustrades by the linear foot. Give the size of newels and the style of treatment. Measure spandrel and stairway paneling the same as wainscoting.

**Fixtures.**—Kitchen dressers may be taken at a fixed price complete, or at a fixed rate per square foot, or as dressed lumber—drawers and doors being taken separately. Wardrobes, bookcases, mantels, and china closets should be treated separately, and a fixed price stated. Porches, exterior balustrades, balconies, porte-cocheres, etc., may be taken at a price per linear foot, or the actual quantity of material may be measured.

## ESTIMATING COSTS

For any molded work which goes through the mill, the usual charge is 1c. per sq. in. of section per lin. ft. of the stuff from which the molding is made, as a base, from which is deducted a percentage, usually 40 to 60%, depending on the grade of the material. For example, a ⅞-in. (undressed thickness, 1 in.) door casing, 5 in. wide, will cost 1c.×5, less say 50%, or 2½c. per lin. ft.

**Baseboard.**—The cost of baseboard material and fitting it in place may be estimated at $1\frac{3}{10}$c. per sq. in. of section per lin. ft. This is for pine; if hardwood is used, 2c. The same rule applies also to chair rails, cap rails, and natural-finish picture molds.

**Paneling.**—Paneling may be estimated at 20c. per sq. ft. for 1-in. pine stuff; if over 1 in., add simply for extra material. If the paneling is of hardwood and veneered, add 100% to price of pine.

**Wainscoting.**—If plain, wainscoting may be estimated at 9c. per sq. ft., the cap being figured separately by the linear foot.

**Door Frames.**—The following estimate represents the approximate cost of an ordinary door frame. This and succeeding estimates are given more to show how to make systematic and accurate estimates than to give any fixed prices.

Cost of a 2′ 8″×6′ 8″ Door Frame in Place

| | |
|---|---|
| 17 lin. ft. of $\frac{5}{4}$″×6″ rabbeted jambs | $ .83 |
| 36 lin. ft. of 1″×5″ casing | 1.17 |
| 36 lin. ft. of 1″×2″ back band | .47 |
| Dadoing and smoothing jambs and casing, 1 hr., at 45c. per hr | .45 |
| Nails | .05 |
| Setting up jambs and casing, 3 hr., at 45c. per hr | 1.35 |
| Total | $4.32 |

The area of the door is 2 ft. 8 in.×6 ft. 8 in. = 17.78 sq. ft. Therefore, the cost of the preceding door frame per square foot of door is 4.32÷17.78 = 24.3c.

**Doors.**—The following estimate gives the cost of a door of moderate price. The size of this door is 2 ft. 8 in.×6 ft. 8 in.×$\frac{6}{4}$ in. It has four panels, is made of No. 1 pine, and is finished with solid ogee molding.

COST OF DOOR IN PLACE

| | |
|---|---|
| Price of door | $4.00 |
| Setting door, putting on hinges and lock, 2 hr., at 45c. | .90 |
| 1 pair of 4″×4″ japanned-steel butts | .16 |
| 1 mortise lock, brass-face, knobs and escutcheon | .70 |
| Total | $5.76 |

If the door is provided with stuck molding instead of solid molding, it will cost about 50c. more. The area of the door is 2 ft. 8 in.×6 ft. 8 in. = 17.78 sq. ft. The cost per square foot is 5.76÷17.78 = 32$\frac{4}{10}$c. The total cost of door and frame per square foot of door is 32$\frac{4}{10}$+23$\frac{3}{10}$ = about 55$\frac{7}{10}$c.

**Window Frames.**—The following estimate gives approximately the cost of a window frame of the size mentioned:

COST OF WINDOW FRAME IN PLACE

*Size, Two Lights, 28 in.×28 in.*

| | |
|---|---|
| Jambs at head, $\frac{5}{4}$″×5″×16′ | $.65 |
| Sill, 2″×5″×4′ | .26 |
| Sub-sill, $\frac{5}{4}$″×6″×2′ 9″ | .14 |
| Blind stop, 1″×2″×16′ | .21 |
| Parting stop, $\frac{1}{2}$″×1″×16′ | .11 |
| Outside casing, $\frac{5}{4}$″×5″×12′ | .49 |
| Head casing, $\frac{5}{4}$″×7″×4′ | .23 |
| Rabbeted cap, $\frac{5}{4}$″×4″×4′ | .13 |
| Molding under cap, 1″×3$\frac{1}{2}$″×4′ 6″ | .11 |
| Sill nosing, $\frac{5}{4}$″×4″×4′ | .13 |
| Inside casing, including apron, 1″×5″×20′ | .65 |
| Back band, $\frac{5}{4}$″×$\frac{5}{4}$″×16′ | .17 |
| Inside stops, $\frac{1}{2}$″×2″×14′ | .10 |
| Four sash pulleys, at 3c. per pulley | .12 |
| Making frame, 1 hr., at 45c. per hr. | .45 |
| Total | $3.95 |

The cost of setting and casing such a window frame is about \$1. The total cost of the frame set in place is therefore $3.95+1.00=\$4.95$.

The cost of the frame per square foot of light is therefore $\frac{4.95\times 144}{2\times 28\times 28}=45\frac{45}{100}$c. or about 46c.

**Sash.**—The cost of an ordinary window with two 28″×28″ lights may be estimated as follows:

COST OF SASH IN PLACE

| | |
|---|---|
| Cost of two sash, $\frac{7}{8}$, double hung, glazed with single-thick American glass | \$2.10 |
| Sash weights, 30 lb., at 2c. per lb. | .60 |
| Cord, 22½ ft., at 1c. per ft. | .23 |
| Two sash lifts, at 5c. each | .10 |
| Sash lock | .15 |
| Setting and hanging sash | .45 |
| Total | \$3.63 |

For curved sash in curved walls, the cost is about twice that of straight work.

**Stairs.**—The cost per step for an ordinary stairway, constructed according to the following specifications, is about \$3.55. For a better class of work, add about one-quarter to this price.

Length of step, 3 ft.; tread, Georgia pine; riser, white pine; open stringer, white pine; nosing and cove; dovetail balusters, square or turned; rail 2½ in.×3 in.; 6-in. starting newel, cherry; two 4-in. square angle newels, with trimmed caps and pendants; simple easements; furred underneath for plastering; treads and risers tongued together, housed into wall stringers, wedged glued, and blocked.

The material of such a stairway will cost about \$1.84 per step. This rate includes landing facia and balustrade to finish on upper floor. The labor on the same, millwork, and setting in place, is about \$1.71 per step. For example, for a stairs having 17 steps and landing balustrade (including return, about 14 ft.), the entire cost will be $17\times\$3.55=\$60.35$, of which \$31.28 will represent cost of dressed lumber, including turned balusters and newels and worked rail, and \$29.07 will

represent cost of labor in housing stringers, cutting, mitering, and dovetailing steps, working easements, fitting and bolting rails, and erecting stairway in building.

**Verandas.**—For small dwellings, it has been found by experience that a veranda built on the following specifications will cost about $3.75 per lin. ft.:

Width, 5 ft.; posts, turned, set 6 to 8 ft. on centers; floor timbers, 2 in.×6 in.; flooring, ⅞-in. white pine, sound grade; rafters, 2 in.×4 in. dressed; purlins, 2 in.×4 in., set 2 ft. on centers; roof sheathing, ⅞-in. matched white pine; box frieze and angle mold; angle and face brackets; steps; no balustrade.

To include balustrade, with 2-in. turned balusters, add about 60c. per lin. ft.

For a veranda, built according to the following specifications, the cost will be $6.75 per lin. ft.:

Width, 8 ft.; columns, 9-in. turned; box pedestals; box cornice and gutter; level ceiling; roof timbers, 2 in.×6 in.; roof covered with matched boards; a good grade of tin; floor timbers, 2 in.×8 in.; floor, 1¼-in. white pine, second grade, with white-lead joints; no balustrade.

Including balustrade, with 2½-in. turned balusters, rail and base to suit, add 80c. per lin. ft.

Where a portion of the veranda is segmental or semi-circular, a close approximation to the cost will result if the girth of the circular part is measured, and a rate fixed at twice that for straight work of the same length. This applies to veranda framing, roofing, casing, and balustrades.

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## ROOFING

### SHINGLES

**Measurement.**—In measuring shingle roofing, it is necessary to know the exposed length of a shingle, which is found by deducting 3 in.—the usual cover of the upper shingle over the head of the third shingle below it—from the length; dividing the remainder by 3, the result will be the exposed length; multiplying this by the average width of a shingle, the product will be the exposed area. Dividing 14,400, the number of

square inches in a square, by the exposed area of 1 shingle will give the number required to cover 100 sq. ft. of roof. For example, it is required to compute the number of shingles 18 in.$\times$4 in., necessary to cover 100 sq. ft. of roof. With a shingle of this length, the exposure will be $\frac{18-3}{3}=5$ in.; then the exposed area of 1 shingle is 4 in.$\times$5 in., or 20 sq. in., and 1 square requires $14{,}400 \div 20 = 720$ shingles.

In estimating the number of shingles required, an allowance should always be made for waste.

Washington red cedar shingles are graded as 18-in. Perfections, 18-in. Eurekas, 16-in. Clears, and 16-in. Stars, and cost about \$6, \$5.50, \$4.50, and \$4 per M., respectively. Cypress shingles are graded as Bests, Primes, Star-A-Stars, and Clippers. Machine-dressed cedar shingles made of swamp cedar are sold by the thousand pieces at approximately the following prices:

| | | |
|---|---|---|
| 6 ″×20″ No. 1, | \$15.00 | per M. shingles |
| 6 ″×20″ A, | 10.50 | per M. shingles |
| 5½″×20″ A, | 9.00 | per M. shingles |
| 5 ″×20″ A, | 8.00 | per M. shingles |

These are superior shingles and are used only on the best work.

Sawed shingles are made up into bundles of 250, and are sold on a basis of 4 in. width for each shingle. If the wider ones are ordered, the cost per thousand is correspondingly increased. For example, if it requires 1,000 of 4-in. shingles to cover a roof area, and 6 in. ones were ordered, only two-thirds as many, or 667, would be needed and furnished, while the cost would be that of 1,000 standard-width shingles.

Shingles cost from \$4 up per M., according to material and grade. Dimension shingles—those cut to a uniform width—of prime cedar, shaved, ½ in. thick at the butt, and $\frac{1}{16}$ in. at the top, will cost \$9 to \$10 per M., but such shingles are usually 6 in. wide and 24 in. long, so that a smaller number will be required per square than of ordinary shingles.

A fairly good workman will lay about 1,000 shingles per da. of 8 hr., on straight, plain work; while, in working around hips and valleys, the average will be about 700 per da.

**Cost.**—The method of estimating the cost of shingle roofing is as follows:

COST OF 1,000 SHINGLES IN PLACE
*Exclusive of Sheathing*

| | |
|---|---|
| 1,000 shingles.......................................... | $6.00 |
| Labor: 1 man can lay 1,000 shingles per da.; wages being $3.80, the cost per thousand is.............. | 3.80 |
| Nails, about.......................................... | .25 |
| (Flashing, about 10c. per sq. ft.) .................. | |
| Cost per thousand, about.......................... | $10.05 |

## SLATING

**Measurement.**—In measuring slating, the method of determining the number of slates required per square is similar to that given for shingling; but, in slating, each course overlaps only two of the courses below, instead of three, as in shingling. The usual lap, or cover of the lowest course of slate by the uppermost of the three overlapping courses, is 3 in.; hence, to find the exposed length, deduct the lap from the length of the slate, and divide the remainder by 2. The exposed area is the width of the slate multiplied by this exposed length and the number required per square is found by dividing 14,400 by the exposed area of one slate.

Thus, if 14″×20″ slates are to be used, the exposed length will be $\frac{20-3}{2}=8\frac{1}{2}$ in.; the exposed area will be $14\times 8\frac{1}{2}=119$ sq. in., and the number per square will be $14{,}400\div 119=121$ slates.

The following points should be observed in measuring slating: Eaves, hips, valleys, and cuttings against walls are measured extra, 1 ft. wide by their whole length, the extra charge being made for waste of material and the increased labor required in cutting and fitting. Openings less than 3 sq. ft. are not deducted, and all cuttings around them are measured extra. Extra charges are also made for borders, figures, and any change of color of the work, and for steeples, towers, and perpendicular surfaces.

## APPROXIMATE COST OF SLATING PER SQUARE

| Classification | Cost of Slate F. O. B. Quarries | Cost of Laying, Including Roofing Felt, and Freight | Total Cost, Exclusive of Builder's Profit |
|---|---|---|---|
| *Black Slate* | | | |
| Brownville, Maine........ | $8.00 | $5.00 | $13.00 |
| Monson, Maine.......... | 7.00 | 5.00 | 12.00 |
| Peach Bottom, Pennsylvania.................. | 6.35 | 4.50 | 10.85 |
| Chapman (Hard Vein), Pennsylvania........... | 6.00 | 4.10 | 10.10 |
| Bangor, Pennsylvania.... | 6.00 | 4.10 | 10.10 |
| Lehigh, Pennsylvania..... | 6.00 | 4.10 | 10.10 |
| *Red Slate* | | | |
| Vermont................ | 10.00 | 4.50 | 14.50 |
| *Green Slate* | | | |
| Vermont................ | 6.00 | 4.50 | 10.50 |
| *Purple Slate* | | | |
| Vermont................ | 5.50 | 4.50 | 10.00 |
| *Mottled Slate* | | | |
| Vermont (Purple and Green)................ | 6.00 | 4.50 | 10.50 |

## TIN ROOFS

In estimating tin (and also other metal) roofs, hips and valleys are measured extra their entire length by 1 ft. in width to compensate for increased labor and waste of material in cutting and laying. Gutters and conductor, or leader, pipes are measured by the linear foot, 1 ft. extra being added for each angle. All flashings and crestings are measured by the linear foot. For seams, addition is made to superficial area depending on the kind of seams used, whether standing, or flat. No deductions are made for openings (chimneys, skylights, ventilators, or dormer-windows), if less than 50 sq. ft. in area; if between 50 and 100 sq. ft., one-half the area is deducted; if over 100 sq. ft. the whole opening is deducted. An extra charge is made for labor and waste of material to flash around such openings.

Two good workmen can put on, and paint outside, from 250 to 300 sq. ft. of tin roofing per da. of 8 hr. Tin roofing will cost from 8 to 10c. per sq. ft., depending on the quality of material and workmanship.

### TILE ROOFS

Tile roofs are constructed of so many styles of tile that no general rules of measurement can be given, and every piece of work must be estimated according to the particular kind of tile used, and the number of sizes and patterns. Information on all these points is to be found in the catalogs of tile manufacturers.

### GRAVEL ROOFING

In gravel roofing, the cost per square depends on the number of thicknesses of tarred felt and the quantity of pitch used per square.

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## LATHING

Lathing is measured by the superficial, or square, yard, no openings under 7 superficial yd. being deducted. Plastering laths are about $1\frac{3}{4}$ in. wide, $\frac{1}{4}$ in. thick, and usually 4 ft. long; the studding is generally placed 12 or 16 in. on centers, so that the ends of the laths may be nailed to them. The laths are usually set from $\frac{1}{4}$ to $\frac{3}{8}$ in. apart, requiring about $1\frac{1}{2}$ and $1\frac{7}{16}$ 4-ft. laths, respectively, to cover 1 sq. ft. For patent plasters, the lath are usually set $\frac{3}{16}$ in. apart on the side walls and $\frac{1}{4}$ in. apart on the ceilings.

For a fair grade of work, a man will lay on an average about 15 bundles, or 1,500 laths, per da. The price usually paid for laying laths is 25c. a bundle.

In the following analysis is given the cost of lathing 100 sq. yd. of surface:

Cost of Lathing 100 Sq. Yd.

| | |
|---|---|
| 15 bundles of laths, at 50c. per bundle | $7.50 |
| 9 lb. of 3d nails, at $3 per 100 lb. | .27 |
| Putting on 15 bundles, at 25c. per bundle | 3.75 |
| Total | $11.52 |

The total cost of lathing 100 sq. yd. is therefore $11.52, or about 12c. per sq. yd.

## PLASTERING

Plastering on plain surfaces, such as walls and ceilings, is always measured by the square yard; but there are considerable variations in detail in the methods of measurement in different sections of the country. The following rules, however, probably represent the average practice, and are equitable to both parties concerned:

On walls and ceilings, measure the surface actually plastered, making no deduction for grounds or for openings of less extent than 7 superficial yd.

Return of chimney breasts, pilasters, and all strips of plastering less than 12 in. in width, measure as 12 in. wide.

In closets, add one-half to the actual measurement.

For raking ceilings or soffits of stairs, add one-half to measurement; for circular or elliptic work, charge double; for surfaces of domes or groined ceilings, charge three prices.

Round corners and arrises (other than chimney breasts) should be measured by the linear foot.

On interior work, increase the price 5% for each 12 ft. above the ground after the first. For outside work, add 1% for each foot above the lower 20 ft.

All repairing and patching should be done at prices agreed upon in advance.

**Stucco Work.**—Cornices composed of plain members and panel work are measured by the square foot. Enriched cornices, with carved moldings, are measured by the linear foot. When moldings are less than 12 in. in girth, measurement is taken by the linear foot; when over 12 in., superficial measurement is used. For internal angles or miters, add 1 ft. to length of cornice; and for external angles, add 2 ft. to length. Sections of cornices less than 12 in. measure as 12 in. Add one-half for raking cornices.

For cornices or moldings abutted against wall or plain surface, add 1 ft. to length of cornice, if against soffit of stairs or other inclined or covered surface, add 2 ft. to length of cornice. For octagonal, hexagonal, and similar cornices, less than 10 ft. in single stretches, measure one and one-half times the length.

For circular or elliptic work, charge double prices; for domes and groins, charge three prices.

Column and pilaster capitals, frieze enrichments, and work of this character, which require artistic treatment, are either made to conform to the models furnished by the architect, or they are modeled from the architect's designs and submitted to him for approval. Expense of modeling is large; prices are usually obtained from specialists in this department.

**Cost of Plastering.**—The following analysis of the cost of plastering for 100 sq. yd., for both three-coat and two-coat work, will be of assistance in making estimates. These costs are exclusive of the lathing, contractor's profit, and all items not mentioned. Three-coat work on wooden lath is generally ⅞ in. thick.

Cost of 100 Sq. Yd. of Three-Coat Plastering

| | |
|---|---|
| *Scratch Coat* | |
| 6 bu. of lime, at 23c. per bu. | $1.38 |
| 9 lb. of hair, at 4c. per lb. | .36 |
| 1 T. of sand, at $1.35 per T. | 1.35 |
| 5 hr., plasterer's time, at 60c. per hr. | 3.00 |
| 5 hr., laborer's time, at 27½c. per hr. | 1.38 |
| Total | $7.47 |
| *Brown Coat* | |
| 6 bu. of lime, at 23c. per bu. | $1.38 |
| 3 lb. of hair, at 4c. per lb. | .12 |
| 1¼ T. of sand, at $1.35 per T. | 1.69 |
| 13 hr, plasterer's time at 60c. per hr | 7.80 |
| 6½ hr., laborer's time, at 27½c. per hr. | 1.79 |
| Total | $12.78 |
| *Finishing Coat* | |
| 3½ bu. of finishing lime, at 35c. per bu. | $1.23 |
| ½ bbl. of plaster of Paris, at $2 per bbl | 1.00 |
| ⅜ bu. of white sand, at 27c. per bu. | .10 |
| 18 hr., plasterer's time, at 60c. per hr. | 10.80 |
| 4½ hr., laborer's time, at 27½c. per hr. | 1.24 |
| Total | $14.37 |

The total cost of 100 sq. yd. of three-coat plaster, then, is $34.62, or about 35c. per sq. yd.

### Cost of 100 Sq. Yd. of Two-Coat Plastering

*Brown Coat*

| | |
|---|---|
| 8 bu. of lime, at 23c. per bu. | $1.84 |
| 16 lb. of hair, at 4c. per lb. | .64 |
| 1⅔ T. of sand, at $1.35 per T. | 2.25 |
| 8 hr., plasterer's time, at 60c. per hr. | 4.80 |
| 4½ hr., laborer's time, at 27½c. per hr. | 1.24 |
| Total | $10.77 |

*Finishing Coat*

| | |
|---|---|
| Same as given for three-coat work | $14.37 |

The total cost of 100 sq. yd. of two-coat plaster is therefore $25.14, or about 25⅛c. per sq. yd.

In patent wall plasters or cements, the ingredients are already mixed in correct proportions and are either neat, that is without sand, or mixed with a suitable quantity of good sand. A good serviceable cement containing sand can be obtained for 30c. to 35c. per bag of 100 lb. The grounds for patent cement plasters on wooden lath are generally ¾ in. An analysis of the cost of plastering 100 sq. yd. with patent cements or wall plasters follows:

### Cost of 100 Sq. Yd. of Three-Coat Plastering

*Scratch Coat*

| | |
|---|---|
| 15 bags (100 lb.), cement, at 30c. per bag | $4.50 |
| 5⅓ hr., plasterer's time, at 60c. per hr. | 3.20 |
| 5⅓ hr., laborer's time, at 27½c. per hr. | 1.47 |
| Total | $9.17 |

*Brown Coat*

| | |
|---|---|
| 12 bags (100 lb.), cement, at 30c. per bag | $3.60 |
| 2 da., plasterer's time, at $4.80 per da. | 9.60 |
| 8½ hr., laborer's time, at 27½c. per hr. | 2.34 |
| Total | $15.54 |

*Finishing Coat*

| | |
|---|---|
| 3½ bags, hydrated lime, at 60c. per bag | $2.10 |
| ½ bbl. plaster of Paris, at $2 per bbl. | 1.00 |
| ½ bu., white sand, at 30c. per bu. | .15 |
| 2 da., plasterer's time, at $4.80 per da. | 9.60 |
| 8½ hr., laborer's time, at 27½c. per hr. | 2.34 |
| Total | $15.19 |

The total cost of 100 sq. yd. of three-coat plaster is therefore \$39.90, or about 40c. per sq. yd. This does not include lathing or profit.

COST OF 100 SQ. YD. OF TWO-COAT PLASTERING

*First Coat*

| | |
|---|---|
| 22 bags (100 lb.), cement, at 30c. per bag | \$6.60 |
| 1 da., plasterer's time, at \$4.80 per da. | 4.80 |
| 1 da., laborer's time, at \$2.20 per da. | 2.20 |
| Total | \$13.60 |

*Finishing Coat*

The finishing coat, as before, will cost \$15.19. The total cost of 100 sq. yd. of two-coat work is, therefore, \$28.79, or about 29c. per sq. yd.

# PAINTING AND PAPERING

## PAINTING

Painting is measured by the superficial yard, allowing additions to the actual surface to compensate for the difficulty of covering deep quirks of moldings, for carved and enriched surfaces, etc. Ordinary door and window openings are usually measured solid, on account of the extra time taken in working around them, cutting in the window sash, etc. Porch and stair balustrades, iron railings, and work having numerous thin strips are also figured solid, for a like reason. Allowance is frequently made for distance from ground that the work is to be done, as in cornices, balconies, dormers, etc., and also for the difficulty of access.

Charges are usually made for each coat of paint put on, at a certain price per superficial yard and per coat.

Graining and marbling (imitations of wood and stone) and varnishing are rated at different prices from plain work.

Capitals and columns and other ornamental work which are difficult to measure, should be enumerated, and a clear description of the amount of work on them should be given.

**Quantities.**—Using prepared or ready-mixed paint, 1 gal. will cover from 200 to 250 sq. ft. of wood surface, two coats;

for covering metallic surfaces, 1 gal. will be sufficient for from 300 to 350 sq. ft., two coats. The weight per gallon of mixed paints varies considerably, but, on an average, may be taken at about 16 lb.

Prepared shingle stains will cover about 200 sq. ft. of surface, per gal., if applied with a brush; or this quantity will be sufficient for dipping about 500 shingles. Rough-sawed shingles will require about 50% more stain than smooth ones.

One pound of cold-water paint will cover 50 sq. ft. for first coat, on wood, according to surface condition, and about 40 sq. ft. of brick and stone.

One gallon of liquid pigment filler, hard oil finish or varnish, will generally cover from 300 to 400 sq. ft. of surface, according to the nature of wood and finish. Ten pounds of paste wood filler will cover about 300 sq. ft.

**QUANTITIES OF MATERIALS**

| Coat | Lead Pounds | Raw Oil Gallon | Japan Drier Gallon |
|---|---|---|---|
| Priming coat...... | 100 | 7 | $\frac{1}{4}$ |
| Second coat....... | 100 | 6 | $\frac{1}{16}$ |
| Third coat........ | 100 | $6\frac{1}{2}$ to 7 | $\frac{1}{16}$ |

One gallon of varnish weighs from 8 to 9 lb.; turpentine, about 7 lb.; and boiled or raw linseed oil, about 8 lb.

For puttying, about 5 lb. will be sufficient for 100 sq. yd. of interior and exterior work.

For sizing, about $\frac{1}{2}$ lb. of glue is used to 1 gal. of water.

For mixing paints, the figures in the accompanying table represent the average proportions of materials required for 100 lb. of lead.

**Cost.**—The cost of applying paint, on general interior and exterior work will average about twice the cost of the materials; while for very plain work, the cost may be taken at about $1\frac{1}{2}$ times that of the materials. For stippling, the cost will be about the same as for $1\frac{1}{3}$ coats of paint. For varnishing, the cost of labor will be about $1\frac{1}{2}$ times the price of

the varnish. The class of work demanded, however, will regulate the actual cost.

The following figures represent fair average prices for various classes of work.

### Interior Work

| *Painting* | *Cost per Square Yard* |
|---|---|
| 1 coat paint, 1 color | $ .12 |
| 1 coat paint, 2 colors | .20 |
| 2 coats paint, 2 colors | .25 |
| 3 coats paint, 2 colors | .30 |
| 2 coats paint, 3 colors | .35 |
| 3 coats paint, 3 colors | .40 |
| 1 coat shellac | .10 |
| Walls, 1 coat size, 2 coats paint | .25 |
| Walls, 1 coat size, 3 coats paint, stipple | .40 |
| *Hardwood Finish* | |
| 1 coat paste filler, 1 coat varnish | $ .30 |
| 1 coat paste filler, 2 coats varnish | .40 |
| 1 coat paste filler, 3 coats varnish | .50 |
| 1 coat paste filler, 3 coats varnish, rubbed with pumice stone and oil | .75 |
| 1 coat paste filler, 3 coats varnish, rubbed with pumice stone and water | 1.00 |
| *Natural Finish* | |
| 1 coat liquid filler, 1 coat varnish | $ .20 |
| 1 coat liquid filler, 2 coats varnish | .30 |
| 1 coat liquid filler, 3 coats varnish, rubbed | .50 |
| Floors, filling, shellacing, varnishing, or waxing, 2 coats | .50 |
| *Tinting Walls—Distemper Color* | |
| Tinting, 50 yards, or less | $ .10 |
| Tinting, 50 yards, or more | .09 |
| Patching and washing walls | .09 |

### Exterior Painting

| *Woodwork* | |
|---|---|
| 1 coat, new work | $ .10 |
| 2 coats, new work, 2 colors | .22 |
| 2 coats, new work, 3 colors | .25 |
| 3 coats, new work, 2 colors | .30 |
| 3 coats, new work, 3 colors | .35 |

| *Brickwork* | *Cost per Square Yard* |
|---|---|
| 1 coat | $ .15 |
| 2 coats | .30 |
| 3 coats | .40 |
| *Sanding* | |
| 2 coats paint, 1 coat sand | $ .28 |
| 3 coats paint, 1 coat sand | .35 |
| MISCELLANEOUS | *Cost of Work* |
| Dipping shingles, per 1,000 | $3.00 |
| Additional coat, per 1,000 | .50 |
| Blinds, per foot, 1 coat | .08 |
| Fence, per foot, 1 coat, 4 ft. high, wood | .12 |
| Iron fence, per foot, 1 coat | .08 |
| Tin roof, per yard, 1 coat | .05 |

## PAPERING

Papering is usually figured per roll, put on the wall. The paper is generally 18 in. wide, and is in either 8-yd. or 16-yd. rolls. On account of waste in matching, etc., it is difficult to estimate very closely the number of rolls required, but an approximate result may be obtained as follows: Divide the perimeter of the room by 1½ (the width of paper in feet); the result will be the number of strips. Find the number of strips that can be cut from a roll, and divide the first result by the second; the quotient will be the number of rolls required. No openings less than 20 sq. ft. in area should be deducted, in order to compensate for cutting and fitting at such places. Add about 15% to the area to allow for waste.

The cost of paper is extremely variable, ranging from 15c. to $6 per double roll; the average cost is probably 25 to 50c. per roll for ordinary houses. Paper hanging costs from 35 to 75c. per double roll, with strips butted, the former figure being for the usual grade of work; with lapped strips, the cost is less, being from 20 to 25c. per roll. A border 18 in. wide costs 5c. per yd. and one 9 in. wide costs 2½c.

## MISCELLANEOUS ESTIMATES

**Plumbing.**—An approximate figure for cost of plumbing is 10% of the cost of the building. This figure is for good materials and labor, and, of course, is subject to considerable variation. For an ordinary house, costing from $1,500 to $3,000, the cost of plumbing may be taken as about 8% for moderate-priced fixtures and public sewer service. The cost of labor alone will average about one-fourth the cost of the materials.

**Gas-Fitting.**—The cost of gas-fitting may be approximately figured as about 3% of the cost of the building. The cost of labor alone varies from about one-fourth to one-seventh the cost of materials. The better the grade of fixtures, the lower will be the ratio—provided there is no excessive ornamentation, requiring much time to put in place—as the cost of labor is about the same for cheap fixtures as for more costly ones.

**Heating.**—The cost of hot-air installation is, approximately, 5% of the cost of the building; for steam heating, 8%; for hot-water, heating, 10%. In estimating on heating by furnace, the average cost of labor is about one-third that of materials. In steam and hot-water heating, the ratio is about one-fifth.

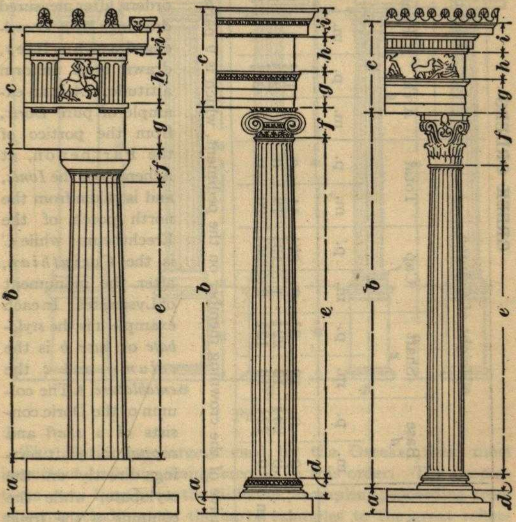
**Hardware.**—Hardware is best estimated by noting the quantities required for each portion of the work as it is being measured, afterwards making these items into a separate hardware bill. Many of the articles, as, for example, the number of fixtures for doors or window trimmings, may be readily counted from the plans. Hardware for windows, doors, etc., is sometimes included in estimating the cost per window, door, etc., and is not considered separately. The cost of hardware depends entirely on the class of work and finish desired, and the best way to estimate on it is, after making the schedule, to select suitable designs and figure the prices from a catalogue. An approximate estimate for ordinary buildings is $1\frac{1}{2}$% of the cost of the building. From 15 to 20% of the cost of hardware will pay for the putting in place.

# ELEMENTS OF ARCHITECTURAL DESIGN

## PROPORTIONS OF THE GREEK AND ROMAN ORDERS

### THE GREEK ORDERS

In proportioning the Greek and Roman orders, a uniform standard of measurement was adopted, so that the several




A B C

parts of the order might be arranged in perfect ratio. This standard consists of *modules* and *parts*. A module is the semi-

**GREEK ORDERS**

| Title | Height of Column | | | | | | | | Height of Entablature | | | | | | | | Ratio of Entablature to Column |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base $d$ | | Shaft $e$ | | Cap $f$ | | Total | | Arch. $g$ | | Frieze $h$ | | Cornice $i$ | | Total | | |
| | m. | p. | m. | p. | m. | p. | m. | p. | m. | p. | m. | p. | m. | p. | m. | p. | |
| Doric ...... | 0 | 0 | 10 | $2\frac{3}{4}$ | 0 | $27\frac{1}{4}$ | 11 | 0 | 1 | $12\frac{2}{3}$ | 1 | $12\frac{3}{5}$ | * | 23 | 3 | $18\frac{4}{15}$ | .328 |
| Ionic....... | 0 | $23\frac{5}{6}$ | 15 | $22\frac{5}{6}$ | 1 | $13\frac{1}{3}$ | 18 | 0 | 1 | $20\frac{3}{4}$ | 1 | $17\frac{3}{4}$ | 1 | $7\frac{3}{5}$ | 4 | $16\frac{1}{10}$ | .252 |
| Corinthian . | 0 | $22\frac{1}{3}$ | 16 | $12\frac{1}{6}$ | 2 | $25\frac{1}{2}$ | 20 | 0 | 1 | $22\frac{1}{2}$ | 1 | 14 | 1 | $18\frac{1}{2}$ | 4 | 25 | .242 |

*Exclusive of the crowning member on the pediment, which is 9 parts high.

diameter of the column, measured at the base, and each module is divided into 30 equal parts. Each diameter, therefore, is equal to 2 modules, or 60 parts.

In the figure on page 377, is shown a diagram of the Greek orders, after measured drawings by acknowledged authorities, drawn to a uniform altitude. *A* is an example of pure *Doric*, from the portico of the Parthenon, at Athens; *B* is the *Ionic*, and is taken from the north porch of the Erechtheum; while *C* is the *Corinthian*, after the monument of Lysicrates. In each example *a* is the *stylobate* or *base*, *b* is the *column*, and *c* the *entablature*. The column of the Doric consists of a *shaft* and *capital*, the shaft resting directly on the stylobate, while the columns of the Ionic and Corinthian have a base, shaft, and capital. The entab-

lature of each order has three divisions—the *architrave, frieze,* and *cornice.*

A comparative statement of the relative values of the divisions of each of the Greek orders is given in the accompanying table on page 378, and is based on the module, or semi-diameter, as the unit of measurement; as previously explained, a part is $\frac{1}{30}$ of this unit.

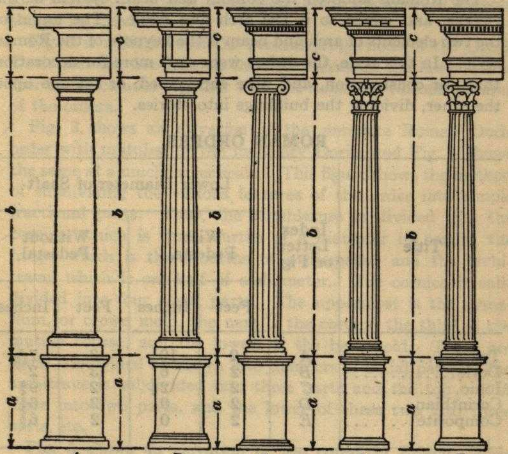



FIG. 1

The Doric was largely used by the Greeks, their most important buildings being erected in this order. The proportions vary largely in the different examples, proceeding from extreme sturdiness in the early examples to the great refinement of the Parthenon, from which the figures of the table were taken. The architrave overhangs the face of the shaft, which is always fluted. The Ionic order was used with much

delicacy by the Greeks. The distinctive capital has scrolls showing on two sides only, although examples of corner scrolls, adopted by the Romans, are also found. The Corinthian order was little used by the Greeks, but the few examples of this style, and especially the one here shown, are unsurpassed for elegance and beauty.

## THE ROMAN ORDERS

The Romans adopted the column and beam system of the Greeks, and joined to it the arch and vault. The union of the two elements of arch and beam is the keynote of the Roman style. In this style, the orders were used more for decoration than for construction, and were superposed, or set one upon the other, dividing the buildings into stories.

### ROMAN ORDERS

| Title | Index Letter on Fig. | Lower Diameter of Shaft | | | |
|---|---|---|---|---|---|
| | | With Pedestal | | Without Pedestal | |
| | | Feet | Inches | Feet | Inches |
| Tuscan | *A* | 2 | $10\frac{1}{4}$ | 3 | $7\frac{7}{16}$ |
| Doric | *B* | 2 | 6 | 3 | 2 |
| Ionic | *C* | 2 | $2\frac{5}{8}$ | 2 | $9\frac{3}{4}$ |
| Corinthian | *D* | 2 | 0 | 2 | $6\frac{3}{8}$ |
| Composite | *E* | 2 | 0 | 2 | $6\frac{3}{8}$ |

The five Roman orders are shown in Fig. 1. *A* is the *Tuscan; B*, the *Doric; C*, the *Ionic; D*, the *Corinthian;* and *E*, the *Composite*. In each of these, *a*, *b*, and *c* represent the pedestal, column, and entablature, respectively. For comparison, the relative values of the lower diameters of the shafts, when the orders are profiled to a uniform total height of 31 ft. 8 in., are given in the preceding table.

The remains of Roman architecture were carefully studied and measured by architects of the Rennaissance Period. They

made drawings of the Roman Orders in which the size of every part was marked in terms of the diameter of the column, which was divided into two modules of 30 parts each. These dimensions are often complicated and difficult to remember. The following figures give details of various orders in terms of the greatest diameter and simple fractions thereof, which may be easily memorized and which will suffice for the execution of drawings and designs made at a small scale. For minute information concerning the Roman Orders the works of Vignola should be consulted.

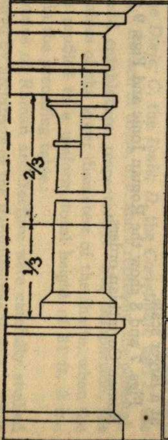
Fig. 2 is a diagram of the general proportions of the Greek Doric and the five Roman Orders in terms of the lower diameter of the column together with the names of various features of the orders.

Fig. 3 shows an elevation of the complete Roman Doric order with mutules, or the mutulary Doric; and Fig. 4 shows the same at a much larger scale. This figure shows the method of subdividing the various features of the order into simple fractional parts. Thus, the entablature is divided into the cornice, which is three-fourths of a diameter in height, the frieze, which is three-fourths of a diameter, and the architrave, which is one-half of a diameter. The cornice is subdivided into four equal parts. The uppermost is the cymatium, or crown mold, the next is the corona, the third is the mutule course, and the lowest is the bed mold. These are again subdivided as shown into numbers of equal parts. The architrave is subdivided into three parts and the top one of these into two parts, and the lower of these two into three parts, etc.

Fig. 5 shows an elevation of the complete Roman Doric order with dentils, or *denticulated Doric*, and Fig. 6 the same at a larger scale.

Figs. 7 and 8 show the Roman Ionic and Figs. 9 and 10 the Roman Corinthian orders.

## COMPARISON OF THE ORDERS




| NAMES OF FEATURES | | | | GREEK DORIC | | TUSCAN | | DORIC | | IONIC | | CORINTHIAN COMPOSITE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ENTABLATURE | 1/4 to 1/5 | CORNICE | CYMATIUM, CORONA, BED MOULD | 2 | 1/2 | 1¾ | 3/4 | 2 | 3/4 | 2¼ | 7/8 | 2½ | 1 |
| | | FRIEZE | | | 3/4 | | 1/2 | | 3/4 | | 6/8 | | 3/4 |
| | | ARCHITRAVE | TÆNIA | | 3/4 | | 1/2 | | 1/2 | | 5/8 | | 3/4 |
| COLUMN | 1 | CAPITAL | ABACUS, ECHINUS, NECKING, ASTRAGAL | 4·6 | 1/2 | 7 | 1/2 | 8 | 1/2 | 9 | 1/3 [1/2] | 10 | 7/6 |
| | | SHAFT | CINCTURE | | | | 6 | | 7 | | 8 | | 8⅓ |
| | | BASE | BASE MOULD, PLINTH | | NONE | | 1/2 | | 1/2 | | 1/2 | | 1/2 |
| PEDESTAL | 1/3 | CAP | CORONA, BED MOULDING | NO PEDESTAL BUT THREE STEPS THE STYLOBATE | | THE CAP IS ONE NINTH THE HEIGHT OF THE PEDESTAL | | | | | | | |
| | | DIE | | | | PEDESTAL 1/3 [VIGNOLA] | | | | | | | |
| | | BASE | BASE MOULD, PLINTH | | | THE BASE IS TWO NINTHS THE HEIGHT OF THE PEDESTAL | | | | | | | |

FIG. 2

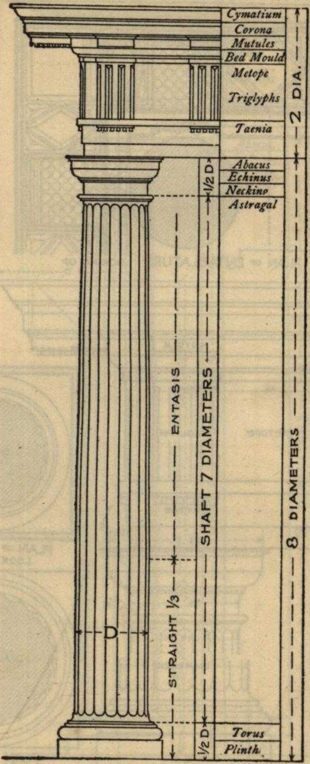

Cymatium
Corona
Mutules
Bed Mould
Metope
Triglyphs
Taenia
Abacus
Echinus
Necking
Astragal
Torus
Plinth
2 DIA.
1/2 D
ENTASIS
SHAFT 7 DIAMETERS
8 DIAMETERS
STRAIGHT 1/3
D
1/2 D

FIG. 3

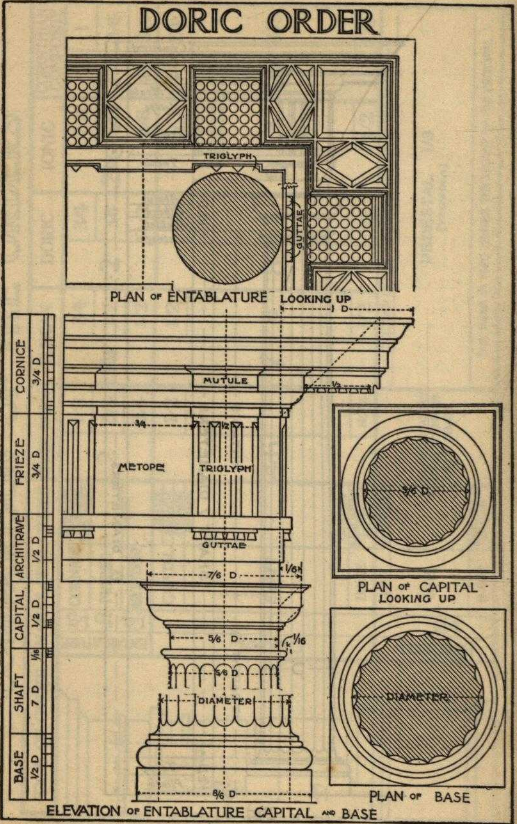

DORIC ORDER
TRIGLYPH
GUTTAE
PLAN OF ENTABLATURE LOOKING UP
D
MUTULE
1/2
3/4
1/2
METOPE
TRIGLYPH
GUTTAE
7/6 D
1/6
5/6 D
1/16
5/6 D
DIAMETER
8/6 D
CORNICE 3/4 D
FRIEZE 3/4 D
ARCHITRAVE 1/2 D
CAPITAL 1/2 D
1/16
SHAFT 7 D
BASE 1/2 D
5/6 D
PLAN OF CAPITAL LOOKING UP
DIAMETER
PLAN OF BASE
ELEVATION OF ENTABLATURE CAPITAL AND BASE

FIG. 4

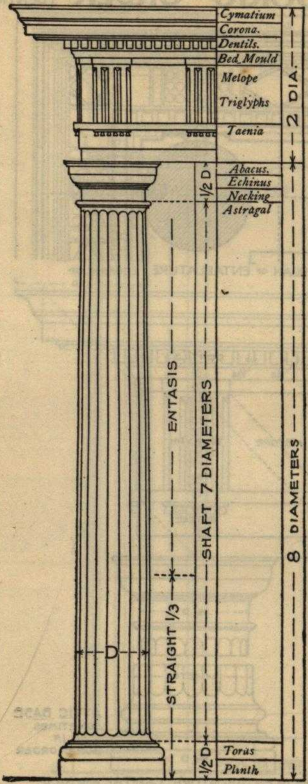

Cymatium
Corona.
Dentils.
Bed Mould
Metope
Triglyphs
Taenia
2 DIA.
Abacus.
Echinus
Necking
Astragal
1/2 D
ENTASIS
SHAFT 7 DIAMETERS
8 DIAMETERS
STRAIGHT 1/3
D
Torus
Plinth
1/2 D

FIG. 5

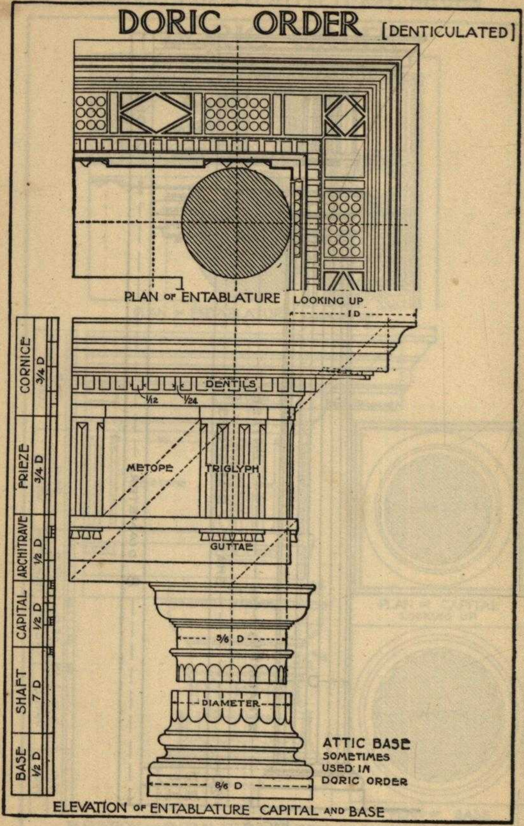

DORIC ORDER [DENTICULATED]
PLAN OF ENTABLATURE LOOKING UP
1 D
DENTILS
1/12
1/24
METOPE
TRIGLYPH
GUTTAE
5/6 D
DIAMETER
8/6 D
CORNICE 3/4 D
FRIEZE 3/4 D
ARCHITRAVE 1/2 D
CAPITAL 1/2 D
SHAFT 7 D
BASE 1/2 D
ATTIC BASE SOMETIMES USED IN DORIC ORDER
ELEVATION OF ENTABLATURE CAPITAL AND BASE

FIG. 6

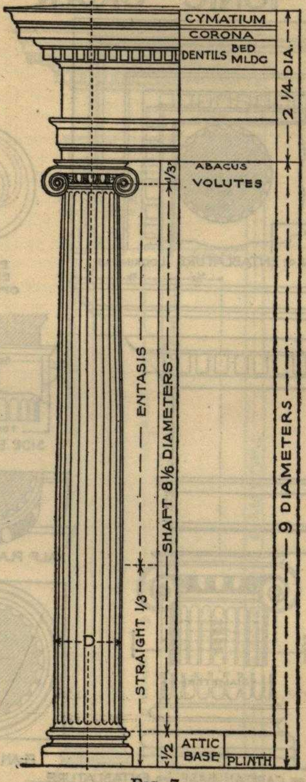

CYMATIUM
CORONA
DENTILS
BED MLDG
2 1/4 DIA.
ABACUS
1/3
VOLUTES
ENTASIS
SHAFT 8 1/6 DIAMETERS
9 DIAMETERS
STRAIGHT 1/3
D
1/2
ATTIC BASE
PLINTH

FIG. 7

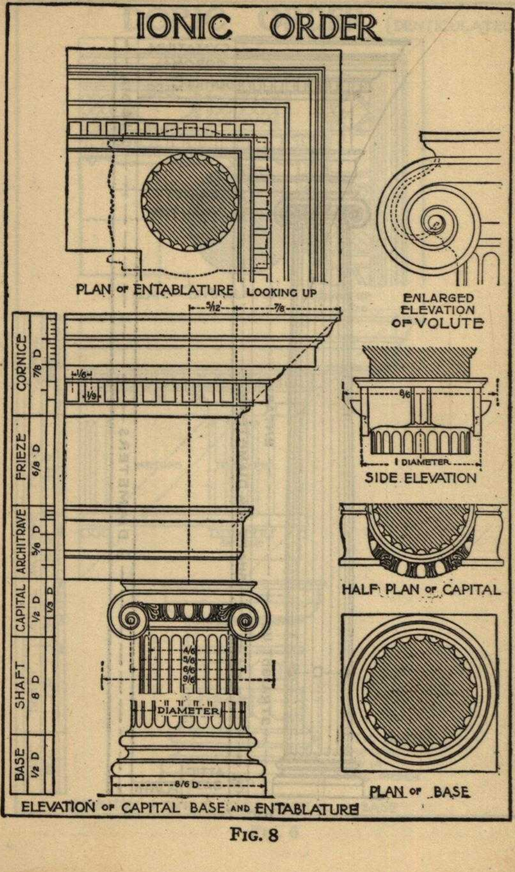

IONIC ORDER
PLAN OF ENTABLATURE LOOKING UP
ENLARGED ELEVATION OF VOLUTE
5/12
7/8
CORNICE 7/8 D
1/6
1/9
FRIEZE 6/8 D
ARCHITRAVE 5/6 D
CAPITAL 1/2 D
1/3 D
SHAFT 8 D
BASE 1/2 D
8/6
1 DIAMETER
SIDE ELEVATION
HALF PLAN OF CAPITAL
4/6
5/6
6/6
9/6
DIAMETER
8/6 D
PLAN OF BASE
ELEVATION OF CAPITAL BASE AND ENTABLATURE

FIG. 8

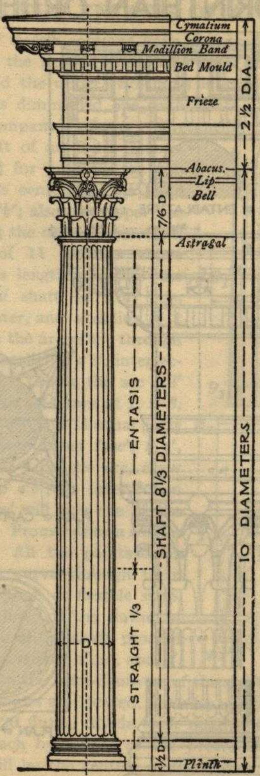

Cymatium
Corona
Modillion Band
Bed Mould
Frieze
2 ½ DIA.
Abacus.
Lip.
Bell
7/6 D
Astragal
ENTASIS
SHAFT 8⅓ DIAMETERS
10 DIAMETERS
STRAIGHT ⅓
D
½ D
Plinth

FIG. 9

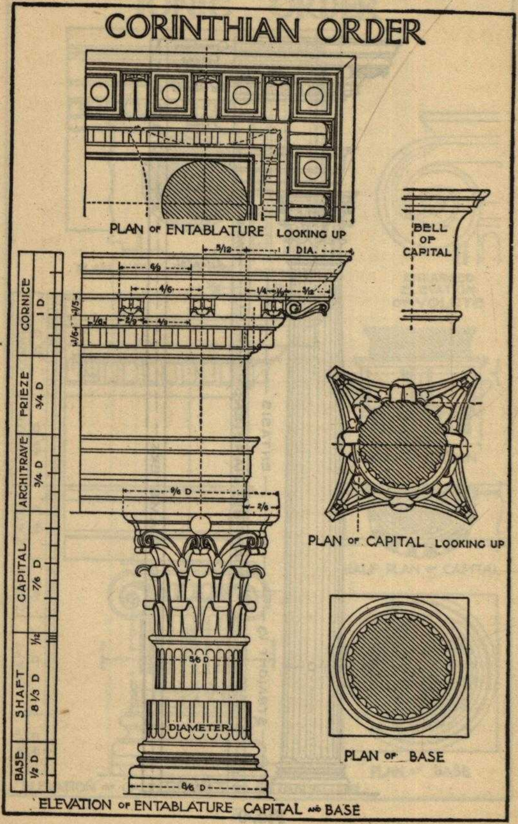
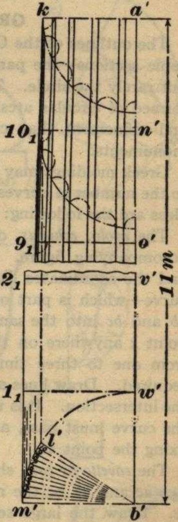

CORINTHIAN ORDER
PLAN OF ENTABLATURE LOOKING UP
BELL OF CAPITAL
5/12
1 DIA.
6/9
4/6
1/4
1/9
5/12
1/6
2/9
4/9
9/6 D
2/6
5/6 D
DIAMETER
8/6 D
CORNICE 1 D
FRIEZE 3/4 D
ARCHITRAVE 3/4 D
CAPITAL 7/6 D
SHAFT 8 1/3 D
1/12
BASE 1/2 D
PLAN OF CAPITAL LOOKING UP
PLAN OF BASE
ELEVATION OF ENTABLATURE CAPITAL AND BASE

FIG. 10

## DRAWING THE ENTASIS OF A COLUMN

The shafts of classic columns have a curved outline called the *entasis*. In the Roman orders the lower third is straight and vertical, and the upper two-thirds is curved. The shaft of the column is diminished one-sixth of its diameter at the neck. The accompanying figure, representing the curved portion of the shaft of an Ionic column, shows a method for profiling the column. Draw the center line $a'b'$, and the base line $m'b'$; also, the upper line $ka'$, representing the neck of the shaft, at a distance of 11 modules above $m'b'$, making its length equal to the semi-diameter of shaft on that line. With $b'$ as a center, and a radius of 1 module, describe the arc $m'w'$; through $k$ draw a line parallel to $a'b'$, intersecting the arc at $l'$. Divide the arc $m'l'$ into 11 equal parts, as shown at *1*, *2*, *3*, etc.; also, divide $a'b'$ into 11 equal parts and draw horizontal lines $1_1 w'$, $2_1 v'$, etc. From point *1* on the arc, draw a line parallel to $a'b'$; its intersection with the line $1_1 w'$ will give one of the required points. From *2* draw a similar line to $2_1$, etc. All the points being marked, draw a curve through them by means of a spline, or flexible strip.




To draw the lines of the fluting of the upper portion of the shaft, proceed as follows: From points $a'$, $n'$, and $o'$, with radii equal to the semi-diameter of the shaft at the section on which these points are located, describe quadrants. As the Ionic shaft has 20 flutes, divide each quadrant into 5 equal spaces of 18° each by means of the protractor; from these points, which will be the centers of the flutes, with a radius equal to two-fifths of the length of arc between the centers of the flutes, describe the semicircles defining the flutes. Pro-

ject the lines of the fillets between the flutes to their position on the horizontal lines *ka'*, etc., by drawing lines parallel to the center line *a'b'*, and through the three points established for the edge of each flute draw a curved line by means of a spline.

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# MOLDINGS

## GREEK MOLDINGS

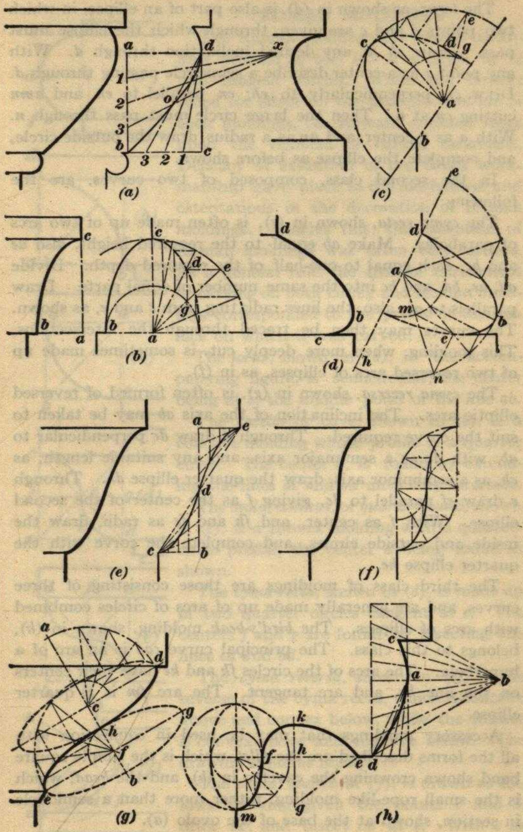
The outlines of the Greek moldings follow the curves of the conic sections—the parabola, hyperbola, and the ellipse—and but rarely the circle. The Roman moldings are nearly always formed of circular arcs, and for this reason lack the delicacy and refinement that characterize the detail of the Grecian monuments.

Greek moldings may be divided into three classes, according to the number of curves composing their outlines. In the first class are the following:

The *ovolo*, *echinus*, or *quarter-round* is shown in (*a*) in the accompanying figure. The point *b*, direction of the axis *ax*, and the coordinates *da* and *ab*, must be determined before the curve—which is part of a hyperbola—can be traced. Divide *ab* and *bc* into the same number of equal parts, and take the point *x* anywhere on the line *ax*—generally at a distance of from one to three times *ad* from *d*, according to the curve required. Draw lines as shown, and trace the curve through the intersection. It is well to assume a point *o* through which the curve must pass, and draw a line from *3* through *o*, thus fixing the point *x*.

The *cavetto* or *cove*, shown in (*b*), is one-quarter of an ellipse. Let *ac* and *ab* be the required height and depth for the cove *bc*. Draw the large semicircle *ce* with a radius equal to *ac*, and the small semicircle *bg* with a radius equal to *ab*. Draw any radius, as *age*. From *g* erect a perpendicular, and from *e* draw a horizontal line intersecting at *d*, a point on the ellipse. Other points may be similarly found.

The *scotia*, shown in (*c*), is also an elliptic curve, having axes inclined to the vertical; it may be drawn as shown for the cavetto.


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)

The *torus*, as shown in (*d*), is also part of an ellipse, in which two points *d* and *c* are given, through which the ellipse must pass. Draw *eh* at any desired inclination through *d*. With any point *a* as a center describe a semicircle passing through *d*. Draw *cm* perpendicularly to *eh*; *cn* parallel to *eh*, and *amn* cutting *cn* at *n*. Then the large circle must pass through *n*. With *a* as a center, and *an* as a radius, draw the outside circle, and complete the ellipse as before shown.

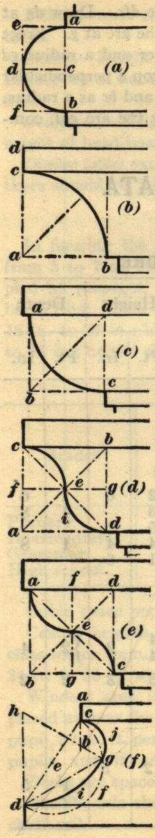
In the second class, composed of two curves, are the following:

The *cyma recta*, shown in (*e*), is often made up of two arcs of parabolas. Make *ab* equal to the required height, also *ae* and *bc*, each equal to one-half of the required depth. Divide *ad*, *ae*, *bd*, and *bc* into the same number of equal parts. Draw parallels to *ab*; also, the lines radiating from *c* and *e*, as shown. The curves may then be traced through the intersections. This molding, when more deeply cut, is sometimes made up of two reversed arcs of ellipses, as in (*f*).

The *cyma reversa*, shown in (*g*), is often formed of reversed elliptic arcs. The inclination of the axis *ab* may be taken to suit the curve required. Through *d* draw *dc* perpendicular to *ab*; with *dc* as a semimajor axis, and any suitable length, as *ch*, as a semiminor axis, draw the quarter ellipse *dh*. Through *e* draw *ef* parallel to *dc*, giving *f* as the center of the second ellipse. With *f* as center, and *fh* and *fe* as radii, draw the inside and outside circles, and complete the curve with the quarter ellipse *he*.

The third class of moldings are those consisting of three curves, and are generally made up of arcs of circles combined with arcs of ellipses. The *bird's-beak* molding, shown in (*h*), belongs to this class. The principal curve *cad* is an arc of a hyperbola. The arcs of the circles *fk* and *ke* have their centers on the line *kg*, and are tangent. The arc *fm* is a quarter ellipse.

Accessory moldings that may be used in connection with all the forms described are the *fillet*, which is the simple square band shown crowning the cavetto in (*b*), and the *bead*, which is the small rope-like molding, rather more than a semicircle in section, shown at the base of the ovolo (*a*).




## ROMAN MOLDINGS

The Roman moldings are almost invariably profiled to the arc of a circle or of two tangent circles. While the Greeks relied for effect on the graceful contour of their moldings, the Romans counted more upon the richness of carved ornament. Delicacy of execution in the Greek workmanship gave place to the mechanical and ostentatious in the decoration of Roman moldings. Besides this, the execution of Roman moldings was often very careless. As a general rule, the lines of enrichment or carving on both Greek and Roman moldings corresponded to the profile of the surface on which it was carved.

The *torus*, shown in (*a*), in the accompanying figure, is semicircular, the center being at *c*, the middle point of the line *ab*.

The *cavetto* or cove, shown in (*b*), is a concave molding whose profile is a quarter circle. The center *a*, is found by extending the lines *dc* and *ba* until they intersect.

The *ovolo*, *echinus*, or *quarter-round*, shown in (*c*), is a convex molding with a quarter-circle profile, the center *d* being found as shown.

The *cyma recta*, shown in (*d*), is made up of two quarter circles tangent at *e*. The centers *f* and *g* are found by bisecting the lines *ca* and *bd*.

The *cyma reversa*, shown in (*e*), is the reverse of the cyma recta, which is concave above and convex below, while the former is convex above and concave below. The drawing explains itself.

The *scotia*, shown in (*f*), is drawn as follows: Having given the points *c* and *d*, draw *cd*, and bisect *cd* at *e*. With *e* as

a center and *ec* as a radius draw a semicircle *dfc*. Draw *dg* at an angle of 30° with the base fillet, cutting the arc at *g*. Erect a perpendicular at *d*, and with *g* as a center and a radius *gd* cut the perpendicular at *h*. Draw *gh* and drop a perpendicular from *c*, cutting *gh* at *b*. With *b* as a center and *bc* as a radius, draw the arc *cjg*. With *h* as a center draw the arc *gid*, completing the curve.

# MISCELLANEOUS DATA

## DIMENSIONS

### DIMENSIONS OF FURNITURE

| Article | Length | | Width | | Height | | Depth | |
|---|---|---|---|---|---|---|---|---|
| | Ft. | In. | Ft. | In. | Ft. | In. | Ft. | In. |
| Bedstead, double | 6 | 6 | 5 | | | | | |
| | 6 | 8 | | | | | | |
| Bedstead, single | 6 | 6 | 3 | | | | | |
| | 6 | 8 | 4 | | | | | |
| Bedstead, three-quarters | 6 | 6 | 4 | | | | | |
| | 6 | 8 | 4 | 6 | | | | |
| Bureau | | | 3 | 5 | 2 | 6 | 1 | 6 |
| | | | 4 | | 3 | | 1 | 8 |
| Cheval glass | | | 2 | | 5 | 6 | | |
| Chiffonier | | | 3 | | 4 | 4 | 1 | 8 |
| Commode | 1 | 6 | 1 | 6 | 1 | 6 | | |
| Lounge | 6 | 4 | 2 | 6 | | | | |
| Piano, concert grand | 8 | 9 | 5 | | | | | |
| Piano, parlor grand | 5 | 6 | 4 | 10 | | | | |
| | 6 | 10 | | | | | | |
| Piano, upright | 4 | 10 | | | 4 | | 2 | 4 |
| | 5 | 6 | | | 4 | 9 | | |
| Sideboard | 4 | | | | 3 | 3 | 2 | 2 |
| | 6 | | | | | | | |
| Table, billiard | 8 | | 4 | | | | | |
| | 9 | | 4 | 2 | | | | |
| | 10 | | 5 | | | | | |
| Table, dining and writing | | | | | 2 | 5 | | |
| Wardrobe | 6 | 9 | 3 | | | | 1 | 5 |
| | 8 | | 4 | 6 | | | 2 | |

*Billiard rooms* should have a 5-ft. clear space all around the table.

*Chairs.*—Height of seat above floor, 18 in.; depth of seat, 19 in.; top of back above floor, 38 in.; chair arms above seat, 9 in.

*Bedsteads.*—Height of foot-boards, 2 ft. 6 in. to 3 ft. 6 in.; height of head-boards, 5 ft. to 6 ft. 6 in.

*Dining tables* extend, on a sliding frame, from 12 ft. to 16 ft.; there should be 2 ft. between the frame and the floor.

## CHURCH SITTINGS

In figuring the floor area of churches, it is usual to allow from 5 to 7 sq. ft. for each person; this includes space occupied by passages, pulpit, etc. Width between pews, back to back, from, 30 in. to 34 in. Length of seat allowed for adults, 18 in. to 24 in.; length of seat allowed for children, 14 in. to to 16 in.; height of seat, 18 in. without cushions.

## SCHOOLROOM DATA

| Grades | Floor Space per Pupil Square Feet | Space for Desks Inches | Blackboards Height from Floor to Top of Chalk Rail Inches |
|---|---|---|---|
| Primary ...... | 12 | 18×12 | 26 |
| Intermediate .. | 14 | 21×13 | 30 |
| Grammar ..... | 16 | 24×16 | 36 |
| High school ... | 18 | 24×16 | |

Cubic space per pupil, 200 cu. ft.

Ceiling heights, class rooms less than 20 ft. wide, 11 ft.; class rooms from 20 ft. to 24 ft. wide, 12 ft.; class rooms from 24 ft. to 28 ft. wide, 13 ft.; play rooms, 8 ft.

Window area in class rooms 20% to 25% of floor area, placed as near the ceiling as possible. Amount of fresh air per pupil, 30 cu. ft. per min. Windows should be at the left of the pupils and if additional light is required at the rear.

Desks are spaced 30 in. back to back.

Blackboards should be 3 ft. 6 in. to 4 ft. high above the chalk rail.

In the auditorium, seats, if without arms, should be 18 in. wide; with arms, 20 in. wide; they should be spaced 30 in. back to back. No seat should have more than six seats between it and the aisle. Aisles with seats on each side should be not less than 3 ft. wide; aisles with seats on one side should be not less than 2 ft. wide.

## STABLE DATA

Inside width of a building with one row of stalls, 18 ft. Height from floor to ceiling, 10 ft. to 12 ft.

Width of horse stalls, 4 ft. or 5 ft. wide by 9 ft. deep; box stall, at least, 9 ft. by 9 ft.

Stable doors, 4 ft. wide and 8 ft. high. Coach house doors, 8 ft. to 9 ft. wide and 9 ft. to 10 ft. high.

Corn bins should be lined with galvanized iron.

## BOWLING-ALLEY SIZES

Length of alley, 65 ft.; width of bed, 3 ft. 6 in.; troughs on both sides. Pit, 5 ft. long, 1 ft. below alley level. Runway, 10 ft. to 12 ft.

## MAXIMUM ALLOWABLE GRADES FOR ROADS

Earth roads, 9 ft. in 100 ft.; gravel roads, $6\frac{1}{2}$ ft. in 100 ft.; Macadam roads, 3 ft. in 100 ft.

Minimum width for two lines of travel, 18 ft.; minimum width for one line of travel, 8 ft., with suitable turnouts provided.

Curves in roads should have a radius of 50 ft. at least. A turn in front of a house should be at least 40 ft. in diameter.

## DIMENSIONS OF VEHICLES

**Automobile Data.**—Dimensions of a 6-cylinder, seven-passenger touring car: Wheel base, 142 in.; width, 5 ft. 8 in.; top down, extreme length, 18 ft. 7 in.; top up, 17 ft. 7 in. Extreme height, top down, 5 ft. 11 in.; top up, 7 ft. 10 in.

Coupe.—Height, 6 ft. 8 in.; length, 19 ft.; width, 6 ft.

Buggy.—Height, 7 ft. 6 in.; length, 14 ft.; width, 4 ft. 10 in.

Hansom and Driver.—Height, 9 ft. 6 in.; length, 18 ft.

Furniture Van.—One-horse, height, 10 ft. 6 in.; length, 22 ft. Two-horse, height, 11 ft.

## MISCELLANEOUS DIMENSIONS

A horse is 7 ft. high, to tips of ears, and 8 ft. long. Three horses hitched abreast are 9 ft. over all.

Standard gauge for railroad tracks, broad, is 4 ft. 8½ in.; narrow, 3 ft.

Freight-house platforms are 4 ft. above track and 5 ft. 6 in. from center of track.

## FORMULA FOR GLAZIER'S PUTTY

The ordinary glazier's putty is a mixture of about 7 parts, by weight, of whiting to 3 parts of boiled linseed oil.

## FORMULA FOR ELASTIC CEMENT

A formula for a good elastic cement used for setting glass in iron or steel sash is as follows:

| | Per Cent |
|---|---|
| Calcium carbonate (extra gilder's whiting) | 70.00 |
| White lead | 14.00 |
| Extra heavy boiled linseed oil | 14.00 |
| Red oil | 1.81 |
| Lampblack in oil | .19 |
| | 100.00 |

# MISCELLANEOUS TABLES

## CAPACITY OF RECTANGULAR TANKS*

| Width Feet | Length of Tank, in Feet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | Number of Gallons for 1 Ft. in Depth | | | | | | | | |
| 2 | 29.9 | 44.9 | 59.8 | 74.8 | 89.8 | 104.7 | 119.7 | 134.7 | 149.6 |
| 3 | | 67.3 | 89.8 | 112.2 | 134.7 | 157.1 | 179.5 | 203.0 | 224.4 |
| 4 | | | 119.7 | 149.6 | 179.5 | 209.5 | 239.4 | 269.3 | 299.2 |
| 5 | | | | 187.0 | 224.4 | 261.8 | 299.2 | 336.6 | 374.0 |
| 6 | | | | | 269.3 | 314.2 | 359.1 | 403.9 | 448.8 |
| 7 | | | | | | 366.5 | 418.9 | 471.3 | 523.6 |
| 8 | | | | | | | 478.8 | 538.6 | 598.4 |
| 9 | | | | | | | | 605.9 | 673.3 |
| 10 | | | | | | | | | 748.1 |

*1 cu. ft. = 7.4805 gal.

### CAPACITY OF CYLINDRICAL TANKS, CISTERNS, ETC.†

| Diameter Feet | Number of Gallons for 1 Ft. in Depth | Diameter Feet | Number of Gallons for 1 Ft. in Depth | Diameter Feet | Number of Gallons for 1 Ft. in Depth | Diameter Feet | Number of Gallons for 1 Ft. in Depth |
|---|---|---|---|---|---|---|---|
| 1 | 5.87 | 5 | 146.88 | 9 | 475.89 | 13 | 992.0 |
| 2 | 23.50 | 6 | 211.51 | 10 | 587.52 | 14 | 1151.5 |
| 3 | 52.88 | 7 | 287.88 | 11 | 710.90 | 15 | 1321.9 |
| 4 | 94.00 | 8 | 376.01 | 12 | 846.03 | 16 | 1504.1 |

†1 gal. = 231 cu. in. = .1337 cu. ft.

## NAILS AND SCREWS

**Nails.**—The following table gives the sizes, lengths, and approximate number of wire nails per pound. The numbers

### SIZES, LENGTHS, AND APPROXIMATE NUMBER OF CUT AND WIRE NAILS PER POUND

| Size Pennies | Length Inches | Approximate Number per Pound | | | |
|---|---|---|---|---|---|
| | | Common Cut | Finishing Cut | Common Wire | Finishing Wire |
| 2 | 1 | | 1,100 | 876 | 1,351 |
| 3 | 1¼ | 430 | 880 | 568 | 807 |
| 4 | 1½ | 275 | 530 | 316 | 584 |
| 5 | 1¾ | 215 | 350 | 271 | 500 |
| 6 | 2 | 150 | 300 | 181 | 309 |
| 7 | 2¼ | 120 | 210 | 161 | 238 |
| 8 | 2½ | 96 | 168 | 106 | 189 |
| 9 | 2¾ | 72 | 130 | 96 | 172 |
| 10 | 3 | 64 | 104 | 69 | 121 |
| 12 | 3¼ | 44 | 96 | 63 | 113 |
| 16 | 3½ | 32 | 86 | 49 | 90 |
| 20 | 4 | 28 | 76 | 31 | 62 |
| 30 | 4½ | 18 | | 24 | |
| 40 | 5 | 14 | | 18 | |
| 50 | 5½ | 12 | | 14 | |
| 60 | 6 | 10 | | 11 | |

given in the table are averages only, and the figures given may be varied either way by changes in the dimensions of heads or points. On page 402 are shown the shapes of nails commonly used for various purposes.

**Screws.**—In the accompanying illustration are shown the two forms of wood screws ordinarily used in carpenter work. Screws are always measured for length from the point to the top of

*Regular Flat Head*

*Regular Round Head*

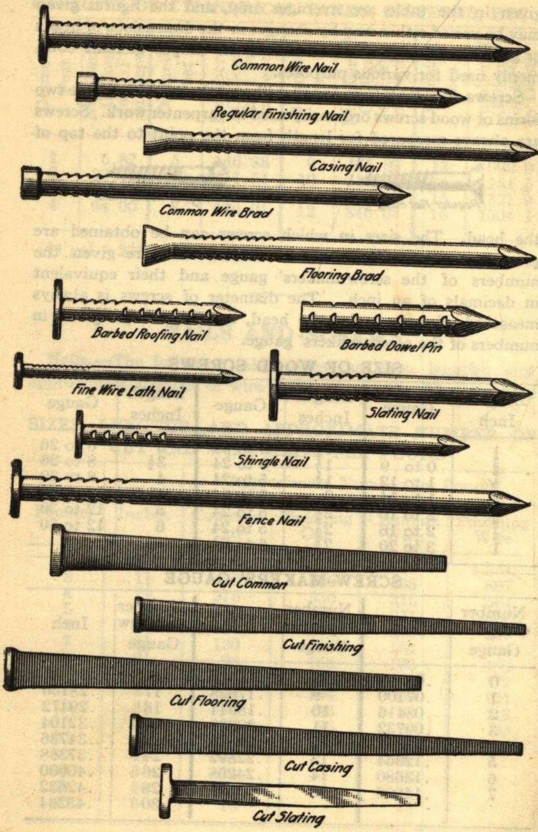
the head. The sizes in which screws can be obtained are given in the following table. In another table are given the numbers of the screw-makers' gauge and their equivalent in decimals of an inch. The diameter of screws is always measured directly under the head, and is always given in numbers of the screw-makers' gauge.

### SIZE OF WOOD SCREWS

| Length Inch | Gauge | Length Inches | Gauge | Length Inches | Gauge |
|---|---|---|---|---|---|
| $\frac{1}{4}$ | 0 to 4 | $1\frac{1}{4}$ | 3 to 24 | 3 | 6 to 26 |
| $\frac{3}{8}$ | 0 to 9 | $1\frac{1}{2}$ | 3 to 24 | $3\frac{1}{2}$ | 8 to 26 |
| $\frac{1}{2}$ | 1 to 12 | $1\frac{3}{4}$ | 5 to 24 | 4 | 8 to 30 |
| $\frac{5}{8}$ | 1 to 14 | 2 | 5 to 24 | $4\frac{1}{2}$ | 12 to 30 |
| $\frac{3}{4}$ | 2 to 16 | $2\frac{1}{4}$ | 5 to 24 | 5 | 12 to 30 |
| $\frac{7}{8}$ | 2 to 16 | $2\frac{1}{2}$ | 5 to 24 | 6 | 12 to 30 |
| 1 | 3 to 20 | $2\frac{3}{4}$ | 6 to 24 | | |

### SCREW-MAKERS' GAUGE

| Number of Screw Gauge | Inch | Number of Screw Gauge | Inch | Number of Screw Gauge | Inch |
|---|---|---|---|---|---|
| 0 | .05784 | 8 | .16312 | 16 | .26840 |
| 1 | .07100 | 9 | .17628 | 17 | .28156 |
| 2 | .08416 | 10 | .18944 | 18 | .29472 |
| 3 | .09732 | 11 | .20260 | 20 | .32104 |
| 4 | .11048 | 12 | .21576 | 22 | .34736 |
| 5 | .12364 | 13 | .22892 | 24 | .37368 |
| 6 | .13680 | 14 | .24208 | 26 | .40000 |
| 7 | .14996 | 15 | .25524 | 28 | .42632 |
| | | | | 30 | .45264 |


Common Wire Nail
Regular Finishing Nail
Casing Nail
Common Wire Brad
Flooring Brad
Barbed Roofing Nail
Barbed Dowel Pin
Fine Wire Lath Nail
Slating Nail
Shingle Nail
Fence Nail
Cut Common
Cut Finishing
Cut Flooring
Cut Casing
Cut Slating

## BOLTS AND TENSION BARS

The strength of bolts in resisting shear and bending may be analyzed similarly to rivets and pins. When bolts or round bars threaded at the end are subjected to tensile stress, they tend to break at the weakest section, which is at the root of the screw thread. In order to make the threaded part equal in strength to that of the body of the rod, the end is sometimes *upset*, so that the diameter at the root of the thread will equal that of the body. Upsetting, however, requires more smithwork, the cost of which may be more than that of the additional material required to increase the size enough to make upset unnecessary.

The following table gives the principal dimensions for United States standard screw threads and nuts, and the diameter at the root of thread of any usual size rod. The strength of any tension may be found by multiplying the area at the root of thread by the tensile stren gth of the material.

EXAMPLE.—Required, the size of a threaded round tension rod, to sustain a stress of 13,350 lb., the safe working tensile stress of the material being 15,000 lb. per sq. in.

SOLUTION.—The area required is $13,350 \div 15,000 = .89$ sq. in. at the root of the thread. Then $.7854\ d^2 = .89$ or $d = 1.06$. From the table, it will be found that a rod $1\frac{1}{4}$ in. in diameter will suffice.

In designing tension bars it would be well to observe the following: Proportion the heads of eyebars so that the bar will break in the body instead of in the eye; the pinhole should be $\frac{1}{50}$ in. larger than the pin; all rivet holes in eyebars should be drilled and the wire edge cut off; bars should be thoroughly annealed after forging, and no smithwork should be done at a blue heat; small tension rods up to, say, $1\frac{3}{4}$ in. square are preferably, either simple loop or clevis rods; the eyes of loop rods should be bored to fit the pin; upset screw ends should have a net section at root of thread 15% greater than the body of the bar; steel rods may be used for upset screw ends, but should be tested in full size section, and thoroughly annealed after forging; clevises, twinbuckles, and sleeve nuts should be of standard approved pattern.

## PROPORTIONS OF THE UNITED STATES STANDARD SCREW THREADS, NUTS, AND BOLT HEADS


| Diam. of Screw. | Threads per In. | Diam. of Core. | Width of Flat. | Inside Diam. | Outside Diam. | Diagonal. | Height of Head. |
|---|---|---|---|---|---|---|---|
| 1-4 | 20 | .185 | .0062 | 1-2 | 37-64 | 45-64 | 1-4 |
| 5-16 | 18 | .240 | .0070 | 19-32 | 11-16 | 27-32 | 19 64 |
| 3-8 | 16 | .294 | .0078 | 11-16 | 51-64 | 31-32 | 11-32 |
| 7-16 | 14 | .344 | .0089 | 25-32 | 29-32 | 1 7-64 | 25-64 |
| 1-2 | 13 | .400 | .0096 | 7-8 | 1 1-64 | 1 15-64 | 7-16 |
| 9-16 | 12 | .454 | .0104 | 31-32 | 1 1-8 | 1 3-8 | 31-64 |
| 5-8 | 11 | .507 | .0113 | 1 1-16 | 1 15-64 | 1 1-2 | 17-32 |
| 3-4 | 10 | .620 | .0125 | 1 1-4 | 1 7-16 | 1 3-4 | 5-8 |
| 7-8 | 9 | .731 | .0140 | 1 7-16 | 1 21-32 | 2 1-32 | 23-32 |
| 1 | 8 | .837 | .0156 | 1 5-8 | 1 7-8 | 2 19-64 | 13-16 |
| 1 1-8 | 7 | .940 | .0180 | 1 13-16 | 1 23-32 | 2 9-16 | 29-32 |
| 1 1-4 | 7 | 1.065 | .0180 | 2 | 2 5-16 | 2 53-64 | 1 |
| 1 3-8 | 6 | 1.160 | ,0210 | 2 3-16 | 2 17-32 | 3 3-32 | 1 3 32 |
| 1 1-2 | 6 | 1.284 | .0210 | 2 3-8 | 2 3-4 | 3 23-64 | 1 3-16 |
| 1 5-8 | 5 1-2 | 1.389 | .0227 | 2 9-16 | 2 31-32 | 3 5-8 | 1 9-32 |
| 1 3-4 | 5 | 1.490 | .0250 | 2 3-4 | 3 11-64 | 3 57-64 | 1 3-8 |
| 1 7-8 | 5 | 1.615 | .0250 | 2 15-16 | 3 25-64 | 4 5-32 | 1 15-32 |
| 2 | 4 1-2 | 1.712 | .0280 | 3 1-8 | 3 39-64 | 4 27-64 | 1 9-16 |
| 2 1-4 | 4 1-2 | 1.962 | .0280 | 3 1-2 | 4 3-64 | 4 61-64 | 1 3-4 |
| 2 1-2 | 4 | 2.175 | .0310 | 3 7-8 | 4 15-32 | 5 31-64 | 1 15-16 |
| 2 3-4 | 4 | 2.425 | .0310 | 4 1-4 | 4 29 32 | 6 1-64 | 2 1-8 |
| 3 | 3 1-2 | 2.628 | .0357 | 4 5-8 | 5 11-32 | 6 35-64 | 2 5-16 |
| 3 1-4 | 3 1-2 | 2.878 | .0357 | 5 | 5 25-32 | 7 5-64 | 2 1-2 |
| 3 1-2 | 3 1-4 | 3.100 | .0384 | 5 3-8 | 6 13-64 | 7 19-32 | 2 11-16 |
| 3 3-4 | 3 | 3.317 | .0410 | 5 3-4 | 6 41-64 | 8 1-8 | 2 7-8 |
| 4 | 3 | 3.566 | .0410 | 6 1-8 | 7 5-64 | 8 21-32 | 3 1-16 |
| 4 1-4 | 2 7-8 | 3.798 | .0435 | 6 1-2 | 7 1-2 | 9 3-16 | 3 1-4 |
| 4 1-2 | 2 3-4 | 4.027 | .0460 | 6 7-8 | 7 15-16 | 9 23-32 | 3 7-16 |
| 4 3-4 | 2 5-8 | 4.255 | .0480 | 7 1-4 | 8 3-8 | 10 1-4 | 3 5-8 |
| 5 | 2 1-2 | 4.480 | .0500 | 7 5-8 | 8 13-16 | 10 25-32 | 3 13-16 |
| 5 1-4 | 2 1-2 | 4.730 | .0500 | 8 | 9 15-64 | 11 5-16 | 4 |
| 5 1-2 | 2 3-8 | 4.953 | .0526 | 8 3-8 | 9 43-64 | 11 27-32 | 4 3-16 |
| 5 3-4 | 2 3-8 | 5.203 | .0526 | 8 3-4 | 10 7-64 | 12 3-8 | 4 3-8 |
| 6 | 2 1-4 | 5.423 | .0555 | 9 1-8 | 10 35-64 | 12 13 16 | 4 9-16 |

The threads have an angle of 60°, wlth flat tops and bottoms, and are of the following proportions:

*Notation of letters. All dimensions in inches*

$D$ = outside diameter of screw;
$d$ = diameter of root of thread, or of hole in the nut;
$p$ = pitch of screw;
$t$ = number of threads per inch;
$f$ = flat top and bottom;
$o$ = outside diameter of hexagon nut or bolt head;
$i$ = inside diameter of hexagon, or side of square nut or bolt head;
$s$ = diagonal of square nut or bolt head;
$h$ = height of rough or unfinished bolt head;

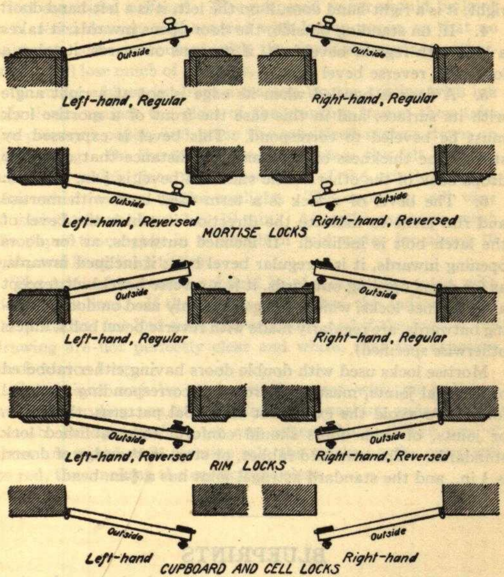
The height of finished nut or bolt head is made equal to the diameter $D$ of the screw.

$$p = \frac{\sqrt{16\,D + 10} - 2.909}{16.64}. \qquad t = \frac{1}{p}. \qquad s = 1.414i.$$

$$d = D - \frac{1.299}{t}. \qquad i = \frac{3\,D}{2} + \frac{1}{8}. \qquad o = 1.155\,i. \qquad f = \frac{p}{8}.$$

# HAND AND BEVEL OF DOORS

In order that hardware may be ordered intelligently, the *hand* and the *bevel* of the door should be given where hardware is not interchangeable, or reversible. Rules to determine the hand of doors have, therefore, been established by the manu-




facturers of hardware, so that the information may be founded on a uniform basis. Reference to the illustration will materially assist in the interpretation of these rules.

1. The hand of a door is always determined from the outside.

2. The outside is the street side of an entrance door, the corridor side of a room-door, and the room side of a closet door. The outside of a communicating door, from room to room, is the side from which, when the door is closed, the butts are not visible.

3. If, on standing outside of a door, the butts are on the right, it is a right-hand door, if on the left, it is a left-hand door.

4. If, on standing outside, the door opens inwards, it takes a lock with regular bevel bolt; if it opens outwards, it takes a lock with reverse bevel bolt.

5. A door is beveled when its edge is not at a right angle with its surface, and in this case the front of a mortise lock must be beveled to correspond. This bevel is expressed by stating the thickness of door and the distance that one edge drops back of the other. The standard bevel is $\frac{1}{8}$ in. in $2\frac{1}{4}$ in.

6. The bevel of a lock is a term used both with mortise and rim locks to indicate the direction in which the bevel of the latch bolt is inclined. If inclined outwards, as for doors opening inwards, it is a regular bevel bolt; if inclined inwards, as for doors opening outwards, it is a reverse bevel bolt (except as to cabinet locks, which, being commonly used on doors opening outwards, are regularly made with reverse bevel bolts, unless otherwise specified).

Mortise locks used with double doors having either rabbeted or astragal joints, must have fronts of corresponding sectional form. To avoid the extra cost of special patterns, the edges, or joints, of such doors should conform to established lock standards. The standard rabbet, or step, in the edge of doors, is $\frac{1}{2}$ in., and the standard astragal joint has a $\frac{3}{4}$-in. bead.

## BLUEPRINTS

Blueprint paper for copying tracings of plans and other drawings may be prepared as follows: Dissolve 1 oz. avoir. of ammonia citrate of iron in 6 oz. of water, and in a separate bottle dissolve the same quantity of potassium ferricyanide in 6 oz. of water. Keep these solutions separate, and in a dark place, or in opaque bottles.

To prepare the paper, mix equal quantities of the two solutions, and with a sponge spread it evenly over the surface. Let the paper remain in a horizontal position until the chemical has set on the surface, which will take but a few minutes; then hang the paper up to dry. In preparing the paper darken the room by pulling down the shades, as direct rays of light affect sensitized surfaces. The prepared paper should be kept in a closed drawer, well covered with heavy paper, so that no light can come in contact with the sensitized surface; otherwise it will lose much of its value.

To make a blueprint from a tracing, lay the tracing with ink side down against the glass of the printing frame, then take the prepared paper, and place the sensitized surface down on the tracing. On the top of the paper place the felt cushion, on top of which place the hinged back of the printing frame, after which expose to the sunlight. The exposure will vary in sunlight from about 3 to 10 min. After the exposure, wash the paper thoroughly in a trough of cold water for about 10 min., and hang it up to dry.

The print after washing should be of a deep-blue color, with clear white lines. If the color is a pale blue, this indicates that the print has not had sufficient exposure, and if the lines of the drawing are not perfectly clear and white, that the exposure has been too long.

Corrections may be made on the print with an ordinary writing or ruling pen and a solution of washing soda, caustic potash, strong ammonia, or any other alkali. When any of these are mixed with carmine ink, the marks on the print will be red, thus making the corrections clear.

## TABLE OF BOARD MEASURE

| Size Inches | Length, in Feet | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 |
| | Number of Feet, Board Measure | | | | | | | | | | | |
| $2 \times 4$ | $6\frac{2}{3}$ | 8 | $9\frac{1}{3}$ | $10\frac{2}{3}$ | 12 | $13\frac{1}{3}$ | $14\frac{2}{3}$ | 16 | $17\frac{1}{3}$ | $18\frac{2}{3}$ | 20 | $21\frac{1}{3}$ |
| $2 \times 6$ | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 |
| $2 \times 8$ | $13\frac{1}{3}$ | 16 | $18\frac{2}{3}$ | $21\frac{1}{3}$ | 24 | $26\frac{2}{3}$ | $29\frac{1}{3}$ | 32 | $34\frac{2}{3}$ | $37\frac{1}{3}$ | 40 | $42\frac{2}{3}$ |
| $2 \times 10$ | $16\frac{2}{3}$ | 20 | $23\frac{1}{3}$ | $26\frac{2}{3}$ | 30 | $33\frac{1}{3}$ | $36\frac{2}{3}$ | 40 | $43\frac{1}{3}$ | $46\frac{2}{3}$ | 50 | $53\frac{1}{3}$ |
| $2 \times 12$ | 20 | 24 | 28 | 32 | 36 | 40 | 44 | 48 | 52 | 56 | 60 | 64 |
| $2 \times 14$ | $23\frac{1}{3}$ | 28 | $32\frac{2}{3}$ | $37\frac{1}{3}$ | 42 | $46\frac{2}{3}$ | $51\frac{1}{3}$ | 56 | $60\frac{2}{3}$ | $65\frac{1}{3}$ | 70 | $74\frac{2}{3}$ |
| $2 \times 16$ | $26\frac{2}{3}$ | 32 | $37\frac{1}{3}$ | $42\frac{2}{3}$ | 48 | $53\frac{1}{3}$ | $58\frac{2}{3}$ | 64 | $69\frac{1}{3}$ | $74\frac{2}{3}$ | 80 | $85\frac{1}{3}$ |
| $2\frac{1}{2} \times 12$ | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 |
| $2\frac{1}{2} \times 14$ | $29\frac{1}{6}$ | 35 | $40\frac{5}{6}$ | $46\frac{2}{3}$ | $52\frac{1}{2}$ | $58\frac{1}{3}$ | $64\frac{1}{6}$ | 70 | $75\frac{5}{6}$ | $81\frac{2}{3}$ | $87\frac{1}{2}$ | $93\frac{1}{3}$ |
| $2\frac{1}{2} \times 16$ | $33\frac{1}{3}$ | 40 | $46\frac{2}{3}$ | $53\frac{1}{3}$ | 60 | $66\frac{2}{3}$ | $73\frac{1}{3}$ | 80 | $86\frac{2}{3}$ | $93\frac{1}{3}$ | 100 | $106\frac{2}{3}$ |
| $3 \times 6$ | 15 | 18 | 21 | 24 | 27 | 30 | 33 | 36 | 39 | 42 | 45 | 48 |
| $3 \times 8$ | 20 | 24 | 28 | 32 | 36 | 40 | 44 | 48 | 52 | 56 | 60 | 64 |
| $3 \times 10$ | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 |
| $3 \times 12$ | 30 | 36 | 42 | 48 | 54 | 60 | 66 | 72 | 78 | 84 | 90 | 96 |
| $3 \times 14$ | 35 | 42 | 49 | 56 | 63 | 70 | 77 | 84 | 91 | 98 | 105 | 112 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 ×16 | 40 | 48 | 56 | 64 | 72 | 80 | 88 | 96 | 104 | 112 | 120 | 128 |
| 4 × 4 | 13⅓ | 16 | 18⅔ | 21⅓ | 24 | 26⅔ | 29⅓ | 32 | 34⅔ | 37⅓ | 40 | 42⅔ |
| 4 × 6 | 20 | 24 | 28 | 32 | 36 | 40 | 44 | 48 | 52 | 56 | 60 | 64 |
| 4 × 8 | 26⅔ | 32 | 37⅓ | 42⅔ | 48 | 53⅓ | 58⅔ | 64 | 69⅓ | 74⅔ | 80 | 85⅓ |
| 4 ×10 | 33⅓ | 40 | 46⅔ | 53⅓ | 60 | 66⅔ | 73⅓ | 80 | 86⅔ | 93⅓ | 100 | 106⅔ |
| 4 ×12 | 40 | 48 | 56 | 64 | 72 | 80 | 88 | 96 | 104 | 112 | 120 | 128 |
| 4 ×14 | 46⅔ | 56 | 65⅓ | 74⅔ | 84 | 93⅓ | 102⅔ | 112 | 121⅓ | 130⅔ | 140 | 149⅓ |
| 6 × 6 | 30 | 36 | 42 | 48 | 54 | 60 | 66 | 72 | 78 | 84 | 90 | 96 |
| 6 × 8 | 40 | 48 | 56 | 64 | 72 | 80 | 88 | 96 | 104 | 112 | 120 | 128 |
| 6 ×10 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 |
| 6 ×12 | 60 | 72 | 84 | 96 | 108 | 120 | 132 | 144 | 156 | 168 | 180 | 192 |
| 6 ×14 | 70 | 84 | 98 | 112 | 126 | 140 | 154 | 168 | 182 | 196 | 210 | 224 |
| 6 ×16 | 80 | 96 | 112 | 128 | 144 | 160 | 176 | 192 | 208 | 224 | 240 | 256 |
| 8 × 8 | 53⅓ | 64 | 74⅔ | 85⅓ | 96 | 106⅔ | 117⅓ | 128 | 138⅔ | 149⅓ | 160 | 170⅔ |
| 8 ×10 | 66⅔ | 80 | 93⅓ | 106⅔ | 120 | 133⅓ | 146⅔ | 160 | 173⅓ | 186⅔ | 200 | 213⅓ |
| 8 ×12 | 80 | 96 | 112 | 128 | 144 | 160 | 176 | 192 | 208 | 224 | 240 | 256 |
| 8 ×14 | 93⅓ | 112 | 130⅔ | 149⅓ | 168 | 186⅔ | 205⅓ | 224 | 242⅔ | 261⅓ | 280 | 298⅔ |
| 10 ×10 | 83⅓ | 100 | 116⅔ | 133⅓ | 150 | 166⅔ | 183⅓ | 200 | 216⅔ | 233⅓ | 250 | 266⅔ |
| 10 ×12 | 100 | 120 | 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 |
| 10 ×14 | 116⅔ | 140 | 163⅓ | 186⅔ | 210 | 233⅓ | 256⅔ | 280 | 303⅓ | 326⅔ | 350 | 373⅓ |
| 10 ×16 | 133⅓ | 160 | 186⅔ | 213⅓ | 240 | 266⅔ | 293⅓ | 320 | 346⅔ | 373⅓ | 400 | 426⅔ |
| 12 ×12 | 120 | 144 | 168 | 192 | 216 | 240 | 264 | 288 | 312 | 336 | 360 | 384 |
| 12 ×14 | 140 | 168 | 196 | 224 | 252 | 280 | 308 | 336 | 364 | 392 | 420 | 448 |
| 12 ×16 | 160 | 192 | 224 | 256 | 288 | 320 | 352 | 384 | 416 | 448 | 480 | 512 |
| 14 ×14 | 163⅓ | 196 | 228⅔ | 261⅓ | 294 | 326⅔ | 359⅓ | 392 | 424⅔ | 457⅓ | 490 | 522⅔ |
| 14 ×16 | 186⅔ | 224 | 261⅓ | 298⅔ | 336 | 373⅓ | 410⅔ | 448 | 485⅓ | 522⅔ | 560 | 597⅓ |

# MEMORANDA

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 SEE FOLLOWING PAGES

## Earns $10,000 a Year

GEO. A. GRIEBLE
ARCHITECT AND ENGINEER
510-12 Columbia Building
CLEVELAND, OHIO

I enrolled with the I.C.S. when employed as a stone cutter. As you will note, my advancement has been quite rapid. First I took the foremanship over 35 stone cutters, and during the winter was promoted to superintendent of the general mason force. Later I was appointed superintendent of general construction for the State of Ohio, which position I held for two and a half years. Then I accepted the position of general superintendent of construction with a general contracting firm in Cleveland, afterward obtaining an interest in the business. After the lapse of four years I disposed of my interest and started an architectural and engineering office. I am handling some of the largest work in this section, mercantile, amusement, and hotel work. I employ from three to four men in the field and six to eight in the office. My present income is from $10,000 to $12,000 per year. I have every reason to be grateful to the I.C.S.

## Some I.C.S. Prize Winners

In an open contest held by *The American Carpenter and Builder,* hundreds of designs were submitted by professional architects from all parts of the United States and Canada. The names of I.C.S. students appeared in the lead as follows: First prize, best design for small residence, I.C.S. Student Charles M. Gates; second prize, design for small residence, I.C.S. Student Joseph A. Riechel; first prize, best design for large residence, I.C.S. Student Alfred J. Danielson; first prize, most modernly equipped residence, I.C.S. Student D. A. Haines; prize winner, small railroad station, I.C.S. Student John Jenkins; prize winner, small church, I.C.S. Student Fred G. Rockwood.

This contest, wherein I.C.S. students carried off the honors in competition with the country's most successful architects, proves conclusively the superiority of I.C.S. training.

## Earnings Increased $70 a Week

I was a journeyman carpenter, averaging less than $25 a week, at the time I enrolled with the I.C.S. for the Complete Architectural Course. I feel that this Course has been of great benefit to me, and I am glad to recommend it to all who wish to advance themselves. I expect soon to open an office as an architect, but I am at present handling two contracts in New York City which have increased my earnings between $70 and $90 a week.

MANSFIELD BARMORE,
135 Wilkinson Ave., Jersey City, N. J.

## A Typical Experience

When I left school I had just reached decimal fractions. I enrolled for your Complete Architectural Course while I was working as a carpenter. I believe that a correspondence course is superior to that of the technical schools, from the fact that the student is usually occupied with the practical side of the work he is studying. I cannot express myself too strongly in praising the I.C.S. for the royal treatment I have received during these years. I am now an architect and my present income reaches as high as $3,000 a year.

M. S. SUTTON,
Room 113, Decker Bldg., Juneau, Alaska

## Income 400 Per Cent. Larger

Your Complete Architectural Course has done more for me than I expected. I find your method of instruction very easy to understand and to put into practical use. Your Course furnishes greater dividends than anything else I know of. Since enrolment my earnings have increased over 400 per cent. and I am now in business as an architect.

ERNEST A. RAUCHSCHWALBE,
1019 10th St., Milwaukee, Wis.

## Repaid 1,000 Fold

I was working as a carpenter, having only a common-school education, at the time I enrolled with the I.C.S. for the Complete Architectural Course. This soon enabled me to enter the contracting business. I am now president of the F. S. Streever Construction Company. The Course has repaid me 1,000 times for the money invested.

F. S. STREEVER,
95 Pleasant St., Ballston Spa, N. Y.

## Office Boy to Bridge Draftsman

When I enrolled with the I.C.S., I was office boy in an architect's office. At present I am employed as a bridge draftsman by a well-known consulting engineer in New York City. My duties are drawing, figuring, computing stresses, weights, etc., detailing, and tracing. When I completed my Course, which took me about 18 months, I was receiving an income 400 per cent. larger than when I began. Today it is 500 per cent. larger, with bright prospects of further increase. I heartily recommend the International Correspondence Schools.

HENRY AUERBACH,
155 Vernon Ave., Brooklyn, N. Y.

## Now a Structural Engineer

When I enrolled in the Mechanical Drawing Course, I was without a job and without money, and had a family of six depending on me. In just a year from the time I enrolled with the Schools, I secured, through your Students' Service Division, a position as mechanical draftsman with a very large firm in Chicago. My next position was as draftsman with the Turner Brass Works, of Chicago, at an increase in salary. Here, the thorough training received from the Schools qualified me to do such work as laying out, making plans and designs, etc., all of which I acquired without any previous knowledge of drafting whatever. I then enrolled for a technical Course, which enabled me to secure a still better position in the structural department of the Illinois Steel Company, where I remained until I came to Denver to take a good position as draftsman with the Victor Fuel Company. I can cheerfully say that the I.C.S. have made me what I am.

H. L. THOMAS, Englewood, Colo.

## Now Secretary and Treasurer

I was detailer and estimator on structural iron and steel work, earning small pay, when I enrolled for your Course, because our firm had either to hire a structural engineer or I must learn to do the work. I am at present doing all the structural engineering for Messrs. A. Lucas & Sons, who employ from 40 to 100 men. I am also secretary and treasurer of the company, besides being a large shareholder in the same. I can assure you that I owe my success entirely to the course of schooling I took with the I.C.S. HUGO LUCAS,
210 Second Ave., Peoria, Ill.

## Now a Successful Manufacturer

When I enrolled with the I.C.S. for a Structural Engineering Course, I was a machinist, earning $71.50 a month. The Course enabled me to design and perfect the rolling and blending machinery manufactured by the Standard Sand and Machine Company. I am now the chief draftsman and superintendent of the above company, at an increased salary. I do not hesitate to recommend the Schools to any one that wants to get out of the rut. I give my I.C.S. training credit for my position with this company. HARRY E. BOUGHTON,
Cleveland, Ohio

## 300 Per Cent. Larger Income

I was working by the day as a bricklayer when I enrolled with the I.C.S. for a Structural Engineering Course. I am now contracting in brick, stone, and cement work and my income has increased 300 per cent. I have from 10 to 20 men at work for me. My advancement is due to hard work and study in the I.C.S. JOHN MATHES, JR.,
21 S. Fair St., Belleville, Ill.

# Another I.C.S. Victory

## Selected from Among 34 Applicants

Nothing could better demonstrate how a man with I.C.S. training "has it on" the average person than the following letter from Mr. Fred W. Howard, 1447 Gates Avenue, Brooklyn, N. Y.:

"Another I.C.S. Victory! Simply told it is as follows: An advertisement in a newspaper called for a junior draftsman for the Dale Company, of New York.

"I answered the ad. To my amazement I found the office crowded with young men looking for the position. By actual count there were 34, all waiting to see the boss.

"When the boss came he asked for samples of work. I was the tenth person to be called on. I submitted three drawings you taught me to make.

"Turning immediately to those who were waiting, the boss said:

" 'I am through interviewing. I have got the man I want.'

"Next morning I reported. I expected to work as a junior, but when I got to the office I found that I was 'it'—a full-fledged draftsman.

"But what has all this got to do with the I.C.S.? In a few words, this: I.C.S. training gave me the *nerve* to *apply* for the position with confidence.

"I.C.S. instruction in drafting enabled me *to get the job* over the heads of 33 others.

"I.C.S. knowledge enabled me to make good *in a position that otherwise would have been too big for me.*" FRED W. HOWARD

Go where you will and you will find that the man with training lands the job. You, too, can secure training. Get it and you have the "bulge" on the other fellow.

# A Contractor With $300,000 Worth of Work Booked

Mr. Lefebvre, the subject of this sketch, last wrote us from the depths of a Canadian winter, under date of December 19th. He is the senior partner of the contracting firm of Lefebvre & Bonin, "Contracteurs Generaux," as they style themselves, for the partners are French-Canadians. You would naturally expect a rather gloomy letter about "rotten business" and "nothing doing in the building line" from a snowed-in and frozen-up builder, with nothing much in sight till spring. But listen!

Mr. Lefebvre says in his letter, "We now have $300,000 worth of work on hand. Enough to keep all hands busily employed until spring." Could anything illustrate better the practical advantages technical education brings? With admirable foresight Mr. Lefebvre had taken many contracts during the previous summer. His reputation for turning out high-class work enabled him to get the business at the highest rates. He had taken on twice as much building as he could possibly complete during the open season, but he pushed the work forward as only the trained contractor knows how to push, and got the outside work finished on all the buildings before winter set in. Then with stoves and furnaces installed, he kept his many workmen cozily and comfortably employed all winter, making many thousands of dollars profit for himself, at a season of the year that otherwise would have been unproductive.

Things weren't always so prosperous with Mr. Lefebvre. Only a few years ago he was a common bricklayer with little education and small knowledge of the English language. To him the letters I.C.S. have meant in very truth, "I Can Succeed."

## Success Against Odds

L. S. Shilling, Architect, Concrete Engineer, and Building Superintendent, is one of the youngest men in the State of Pennsylvania qualified to bear these impressive titles. Most men of twice his years have to content themselves with a single branch of the profession. But Mr. Shilling, while still a young boy at home, set a high mark for himself and never wavered in his determined struggle to reach it.

Where most boys have only the warmest approval and cooperation from those around them, Shilling was very often called away from his studies. He was loaded with home duties, by those having all too little faith in his natural ability to raise himself to a position of power and affluence. Under such discouraging circumstances many boys would have given up, perhaps lost faith in themselves and ambition for the future, but not so Shilling. Always he returned to his studies with renewed courage to work out a successful career.

Today he is reaping the reward of those months of faithful effort in spare-time study. His friends now appraise him at his true worth. Respected by his business associates for his brilliant attainments and high professional standing, consulted on every occasion by those contemplating construction work in his line, he has become one of the recognized leaders in his chosen profession.

Many boys of excellent natural ability must suffer from lack of appreciation by those who should best know their true worth. Those who persevere, as did Mr. Shilling, win in spite of every obstacle.

# Another Successful Contractor

Mr. Charles I. Rice was born in Delevan, Colusa County, California, November 27, 1887. He finished grammar school, but was obliged to give up higher education on account of the long illness and subsequent death of his father, which made him the responsible head of the family.

Placed under the necessity of finding immediate employment, he took the first job that offered, as helper to a carpenter. In all his young life, he had never dreamed of such a thing as becoming a carpenter or builder; much less an architect. Circumstances, good luck, Providence, call it what you will, had simply led him in the right direction. Even to his youthful eyes it soon became apparent that wonderful opportunities awaited the trained architect and builder. Again fortune favored him. He learned of the I.C.S. Courses in Architecture and the Building Trades and quickly enrolled, paying a small sum down, and the balance by the month. As he progressed with his studies he soon found he was able to handle a better class of work. After a few months he was made foreman for a large contractor at good pay. But a young man of Mr. Rice's stamp, full of ambition and eager to make a place for himself in the world, could not long be satisfied in a subordinate position, and a little later we find him in business for himself, keeping ten to fifteen men on his own pay roll and subletting many jobs to others whose lack of special training in the higher branches of contracting and building construction forever bars them from taking these profitable contracts in their own name. In such cases Mr. Rice assumes responsibility for the job as a whole, lets others do the actual work, and keeps the major share of the profits for himself.

Good luck, you may say, accounts for the success of this California boy. Yes! But it was good luck mixed with a lot of faithful study and constant application of the facts and principles learned in his I.C.S. Course.

## Made a Fortune of $50,000

After finishing his public-school education, Samuel Tilden Norton, the I.C.S. student, chose Architecture as his future profession.

Already familiar with the well-tried methods of correspondence instruction in the I.C.S. Architectural Courses—many of his older friends being then well on the road to success as the result of their Courses—Mr. Norton lost no time in commencing his studies. His advancement followed naturally and quickly.

From a position as Architectural Draftsman in the office of Cariere & Hastings, of New York City, he was soon promoted to a more responsible position in the drafting room of Architect John Galen Howard, of New York. Having become a first-class draftsman, Norton continued his diligent study of the higher branches of Architecture in the Complete Architectural Course, and was thus ready for further advancement when opportunity offered.

His chance came quickly in the shape of a fine offer from the great Architectural firm of Barney & Chapman, also of New York. This was Mr. Norton's last salaried position.

Four years after enrolling for his Course he removed to Los Angeles and soon was recognized as a leading architect of that progressive city. Although still a young man he is now worth at least $50,000—a pretty good indication of the liberal fees awaiting the trained architect.

Mr. Norton's record is a simple story of success, gained quietly, consistently, one step at a time. The element of "luck" never entered into it. He had no powerful friends to boost him along. He holds his present enviable position entirely as the result of earnest, persistent effort in preparing himself for advancement. There is nothing in his modest achievement that any faithful I.C.S. student may not hope to equal.

# Never Too Late to Begin

A carpenter, late in life, found the way to make his declining days the pleasantest and most remunerative of his whole career. He tells how in the following letter:

"I learned the carpenter's trade while quite a young man, but soon felt keenly the need of a technical education to master the problems in my work. Unable to attend college, the best I could do was to attend night school. In the course of thirty years I had spent a great deal of money on textbooks and so-called self-instructors, but entirely without success. At last I learned of the International Correspondence Schools, and my only regret is that they did not exist thirty years ago.

"I had no trouble in understanding the Complete Architectural Course. My instructors taught me everything by mail, easily, simply, and accurately. The value of what I learned is shown by the fact that I now have an architectural office in this city and am doing well.

"I would recommend the International Correspondence Schools to every one ambitious to succeed. The cost of an I.C.S. Course is insignificant, compared with the benefits derived." (Signed) James Kelly,

2112 Fulton St., Brooklyn, N. Y.

Mr. Kelly's case illustrates once again, as it has been illustrated many times before, that age has nothing to do with successfully completing a Course. It is merely a question of determination to make something of one's self. There is more reason for a man of mature years to educate himself than for a young man to do so. A young man, if necessary, is able to do work requiring physical powers; the old man, on the contrary, must find something easy, and unless he is qualified through education for some field of work necessitating little physical exertion, he is compelled to accept menial employment, at low wages, when he is physically unable to perform the hard work in connection with his chosen profession.

Mr. Kelly found the way to success late in life. Many others are following his example.

## Two Great Office Buildings

You will find in New York City the greatest office buildings in the world. Among the best known are the new Equitable and the Fifth Avenue Buildings. I.C.S. Student H. S. Gardner supervised the erection of the Equitable Building, and I.C.S. Student David Larkin is Chief Engineer of the Fifth Avenue Building.

Mr. Gardner is an I.C.S. enthusiast. He states:

"In my experience as an employer I have found that I.C.S. students are more efficient and painstaking workmen. I employ them wherever possible."

Mr. Larkin is now earning in the neighborhood of $4,000 a year. His advice to those ambitious to succeed is to enroll for an I.C.S. Course.

## An Enthusiastic Student's Testimony

The following letter from our student, George Pfleghardt, 1725 Arapahoe Street, Los Angeles, Calif., is a sample of what enthusiastic students are sending to us, to show what the International Correspondence Schools have done for them:

"I am going to try to express my feelings toward the I.C.S., but as my school life was cut short and I have had to hustle for a living since the age of 12, I am afraid I will fall short in trying to express myself. At 18 I began the carpenter trade, studying all the books I could get. One evening, going home from work, I found one of your circulars on a sidewalk. I took it home, read it, and immediately signed up for a Complete Architectural Course. My wages at that time were small, but I soon doubled them under your instruction. I am now a contractor in business for myself and do not fear to undertake anything that comes around, because of what I have learned from the Schools and with your textbooks to refer to. My income has increased more than 100 per cent. I draw my own plans, and am picking up quite a nice business. I wish to offer my sincere thanks to the I.C.S. for the good they have done me."

# From the New Jersey State Board of Architects

The New Jersey State Board of Architects in its second annual report, in recommendations under the heading of "Books for Study," makes the following statement indorsing the International Correspondence Schools' Courses of study:

"The Board having received numerous inquiries concerning the extent of the preparation necessary to fit one to engage in an examination for a certificate to practice architecture in the State, it has been thought best that the following information be issued:

"The Board recommends, where it is possible, that the student complete a full course in architecture at some well-known university or other institution of learning. A diploma of graduation supplemented by a proper amount of experience is sufficient evidence to the Board that the applicant for a certificate is worthy of one and that the formal examination may be waived.

"The Board realizes that to many this is impossible and to such **it can recommend the Courses of study conducted through the mails by the International Correspondence Schools, Scranton, Pa. Any one who has taken one of these Courses will be well prepared to pass the Board's examination."**